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GEOPHYSICS

A Journal of General and Applied Geophysics

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The Society of Exploration Geophysicists

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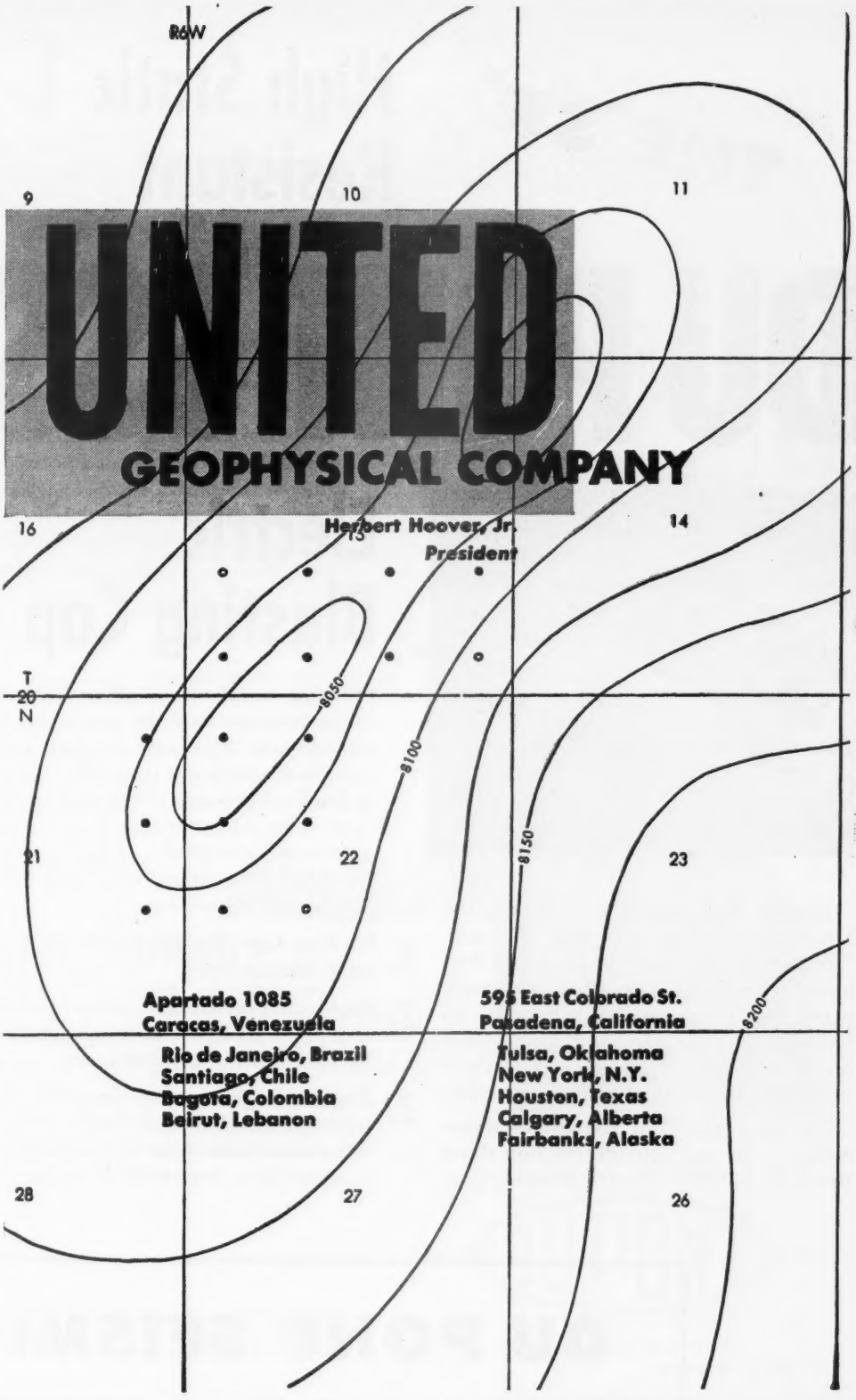
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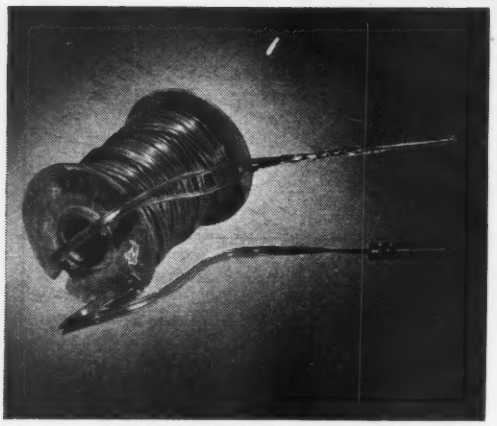

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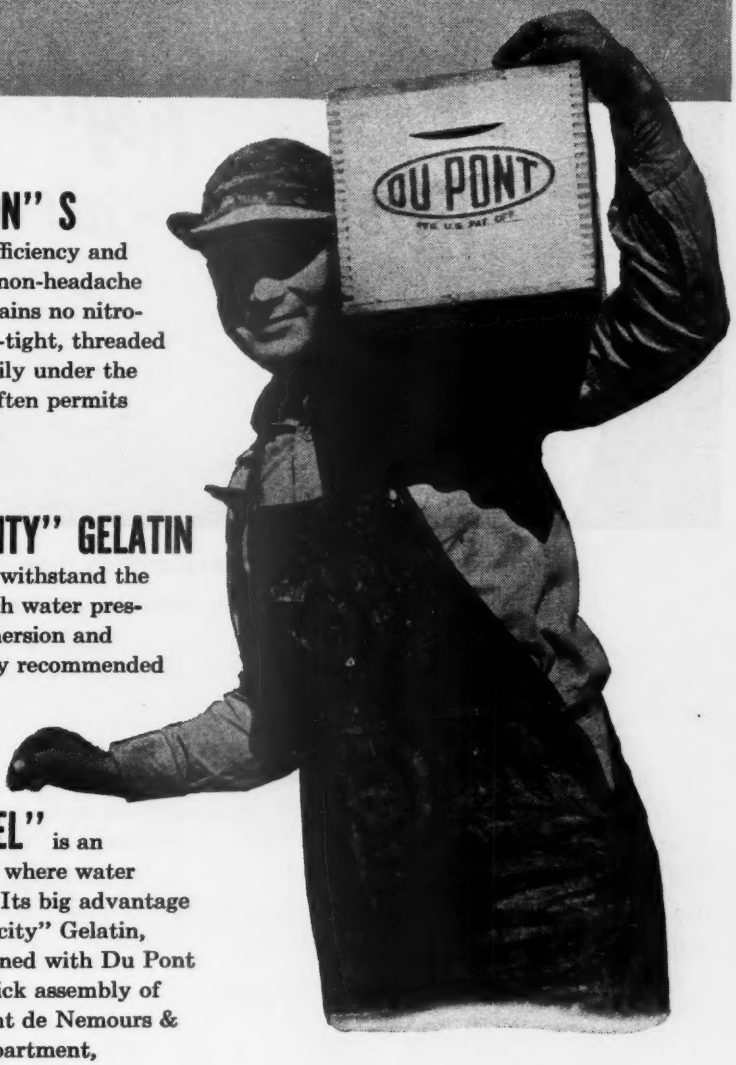

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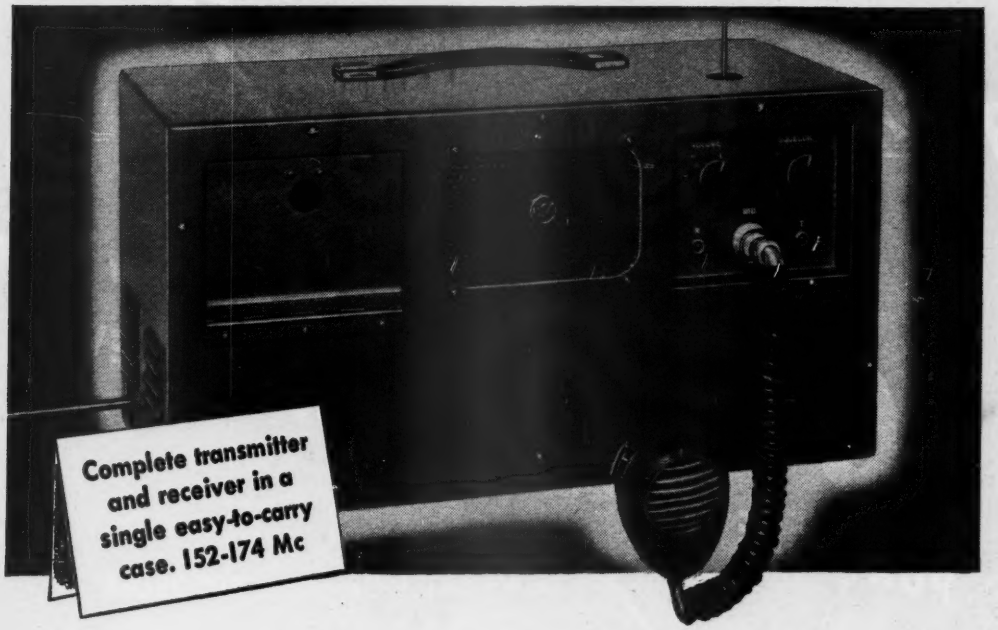

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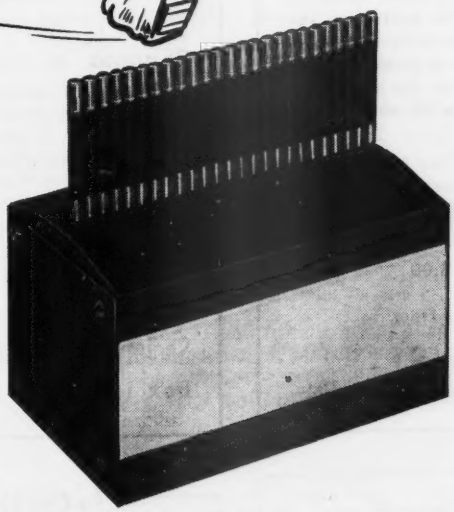

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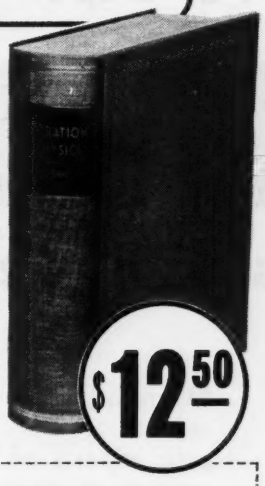

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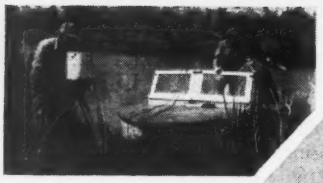

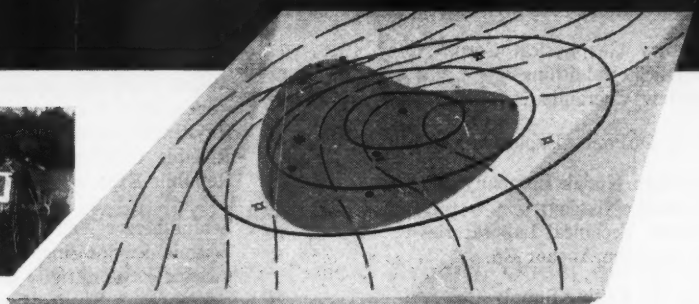

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GEOPHYSICS

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THE STATE OF SEISMIC PROSPECTING*

ANDREW GILMOUR†

The application of physics to the search for minerals and especially for petroleum began in earnest after the first World War. As Weatherby has stated in his excellent paper on The History and Development of Seismic Prospecting (1940) "the stage had been carefully set and the players were ready to perform their new roles as prospectors." Minthrop in Germany and Karcher, Hasemann, Eckhardt, and McCullom in this country were considering the use of artificial seismic waves in finding oil-bearing structure. Ferdinand Suess in Hungary was building Eötvös torsion balances and the Askania Company in Germany was constructing torsion balances and magnetometers.

Field parties started out with torsion balances, magnetometers, and seismic equipment in the early 1920's. The directors and operators on these parties were pioneers. There was no background of operations or experience upon which they could draw. They believed, and the men and oil companies backing them believed, that small differences in travel time of sound waves and small variations in gravity and magnetism would yield indications of structures favorable for accumulation of oil, and the events quickly justified their belief.

In seismic prospecting, a pulse or sound wave is caused by the explosion of a charge of dynamite on or near the surface of the ground. As this pulse travels through the earth it is in part reflected, in part refracted at successive layers; its velocity increases or decreases depending on the material it traverses; it suffers attenuation, dispersion, distortion, and interference; and yet at the end it appears on the record as a recognizable correlatable pulse whose travel time is measured to a thousandth of a second. This travel time then undergoes correction for weathering, for elevation, and for frequency variations, and is compared with the travel times from nearby shot points.

In the years 1925 to 1930 many shallow salt domes in the Gulf Coast of Texas and Louisiana showed refraction "leads" of the order of five-tenths of a second; that is, the travel time for, let us say, a six-mile shot across a dome was five-tenths of a second less than the travel time for the same length shot in a direction

* Address of Retiring President, Society of Exploration Geophysicists, presented at the joint meeting, A.A.P.G., S.E.P.M., and S.E.G., Chicago, April 25, 1950. Manuscript received by the Editor April 10, 1950.

† Amerada Petroleum Corporation, Tulsa, Oklahoma.

in which there was no dome or structure. The slope of a time-distance curve plotted from a profile across the dome usually showed salt velocity. It was recognized that, in this area, leads of two- or three-tenths of a second, while not showing salt velocity, were definite indications of structure, probably deep-seated domes. By 1935 more careful surveying, improvements in instrumentation, and improvements in representation and interpretation of the data were such that, in the Gulf Coast, a lead of five-hundredths of a second on a six-mile shot was just as definite an indication of a deep-seated structure as a lead of two-tenths of a second. A lead of three-hundredths of a second was just about the limit of error of the method but was worth checking.

In 1929 and 1930 the reflection method, by its greater accuracy of location and greater resolving power, largely replaced the refraction method. It had its early successes in central Oklahoma where Pennsylvanian, Hunton, and Viola limestones gave reflections which could be correlated, from shot points spaced a mile apart, over considerable distances. In other areas such as East Texas, the Conroe Trend, the Mexia-Luling fault line, southern Louisiana, parts of West Texas, Alabama, Colorado, Nebraska, New York, Pennsylvania, and Illinois similar "spot" correlations were made from one or more horizons during the 1930's. It was soon found, of course, that the quality, character, and persistence of reflections varied widely from area to area. In areas where the quality and character were poor shot points had to be put closer together. This led naturally to continuous profiling. In the Gulf Coast of Texas and Louisiana and in California "dip" methods evolved. In these areas a number of reflections could be obtained from one shot point but different reflections would be obtained from the next. Often one reflection or several reflections would carry over, at most, two or three profiles. The dips of the reflecting beds could be computed from these reflections. The longer the uniform dip segment the more accurate the dip.

As stated earlier the men who designed, built, and assembled the equipment and the men who directed and carried on the early field operations could not draw on any background of experience but they had the educational background, the ingenuity, the industry, the interest, and the common sense which insured progress. As the years passed the progress was rapid. The amount of work done and the number of parties in the field expanded rapidly, but the improvement in instruments, the quality of the work done, and experience and ability in interpretation generally kept pace.

Then came the war. As an essential part of an essential industry companies doing geophysical work were allowed to retain most of their supervisors, party chiefs, chief observers, and chief computers. But the men just under these ranks, in fact most of the other personnel, were prime material for the services. So that during the war field parties hobbled along with inferior personnel, little improvement in instrumentation, and often wornout field equipment. In spite of this, the number of seismograph parties in the field expanded, according to Eckhardt, (1948), from just over 200 at the end of 1941 to 350 at the end of 1945. The urgency of the war effort necessitated the expansion in exploration in order to

insure the availability of adequate supplies of petroleum for that stupendous effort, even though that expansion entailed a large loss of efficiency. Taking into account the pressure on experienced personnel, the calibre and lack of experience of available help, the difficulty and delay in obtaining instruments and equipment or even in obtaining materials for the repair of instruments and equipment, the job done during the war years was one of which geophysicists can be justly proud.

After the war the seismograph parties in the field continued to increase rapidly in number. At the end of 1948 there were more than 500 in the United States. That was more than two and one-half times the number in 1941. As stated above, the services had taken nearly all the junior men. Those were the men who, by education or experience or both, should have been ready and available for responsible positions when the expansion came. When the war ended these men had been out of geophysical work for three or four years. During that same period the colleges had not, of course, been turning out replacements. The result was that during the period of greatest expansion of geophysical prospecting there was, as Eckhardt has pointed out, an acute shortage of suitably trained technical personnel (1948).

In twenty five years of seismic exploration in the United States much of the prospective oil-producing area has already been carefully detailed. This is especially true of areas in which there are large anticlines which can be easily mapped. Already exploration has pushed its way into those areas where obscure traps remain undiscovered because of their poor accessibility, their borderline value, or their lack of seismic distinction. In such areas low-relief structures must be painstakingly delineated. The differences in travel time on low-relief structure are often less than one-hundredth of a second. To insure that such small differences are dependable, the instruments have to be designed, built, and matched with great care and precision and field operations have to be carried out in such a way that data of the highest quality possible and of the greatest accuracy possible is obtained.

I submit that during the past five years many of our operations have not measured up to the standard that should be required and expected. Before the days of the expander or automatic volume control it was necessary to take several shots to cover the whole range of desired reflected times. The number of shots which had to be taken depended a great deal on the experience and ability of the observer and shooter. But with the introduction of the expander or automatic volume control reflections could, theoretically, be picked from just beyond the first breaks out as far as sufficient energy persisted on the record. Too often the observer decided that all he had to do was to shoot a very large charge of dynamite and move on to the next shot point. Frequently energy persisted on the record far beyond the time at which a reflection from the basement rocks should come in. The use of too much dynamite to bring in a given reflection lowers the contrast between the reflection and the noise on which it is superimposed by stepping up the noise level. The result is a poor record. In an area where the quality is poor the reflection may not be recognizable. In many cases the ex-

pander or automatic volume control is built in to take effect before the first break so as to make the lines appear steady. Then far too large a charge of dynamite has to be used to get the reflection level above the noise, resulting usually in a very poor or useless record. The expander or automatic volume control, when properly used, is of great assistance in getting good reflection data more cheaply by cutting down the number of shots and the number of holes required. But it is too often used as a screen behind which poor instrument work, due to inexperience, lack of technical skill, or sheer laziness, can be hidden. Its misuse and consequent lowering of record quality should usually be blamed directly on the observer and party chief.

The effort to obtain better-looking records has led to use of multiple geophones and mixing. When a number of geophones, say two or five or ten, are connected to one amplifier and galvanometer, that is, to one trace, without interconnection between the traces the records are taken with multiple geophones. When the traces are interconnected, that is, when the output of a geophone is fed into more than one trace, the records are "mixed." The use of multiple geophones often improves the quality of the records in areas where record quality is poor, provided the observer and his helpers keep the geophones in good condition. But it is much more difficult to keep forty or a hundred or five hundred geophones in condition than it is to keep ten or twenty. Again the burden is on the observer and party chief. Mixing, like multiples, gives better-looking records but increases tremendously the uncertainties in interpretation because a burst of energy on one trace may dominate all the traces into which it is fed.

The quality of the records and the interference pattern which is recognized as reflection character depend on the natural frequency of the recording circuit as well as on the attitude of and interval between reflecting horizons. When a survey is begun in a new area the observer should experiment with the bands of frequency, that is, filter settings, available to determine at which setting the reflection will come in best. And if reflection quality deteriorates he should experiment again to get the best result. But any change in filter setting from shot point to shot point must be noted and corrected for because the change in filter setting will make a change in the reflection time picked and that change in time may be as great as the change due to structural relief. Again the result depends on the technical skill of the observer and party chief and on their appreciation of the fact that the time intervals on records from successive shot points must be comparable to a few thousandths of a second.

Too many records have been turned in with questionable time-breaks and questionable up-hole times. A good time-break is a necessary requirement of seismic prospecting because it is the base from which all the other times are taken. The weathering correction made by most operators depends on the up-hole time. There can be no excuse for the continued recurrence of poor time-breaks and poor up-hole times. They show lack of skill and experience or, more likely, lack of interest in their work on the part of the observer and shooter. Poor time-breaks and poor up-hole times are merely symptoms of poor workmanship and unreliable operations.

This discussion leads to the conclusion that the quality and reliability, as well as the amount, of the work a company gets from the seismograph party it employs depends much more on the training and technical skill, on the experience, on the ability and industry, on the common sense and common honesty of the observer and party chief than it does on the eminence and reputation of the executives of the geophysical company or department. Close competent supervision of field operations certainly helps but the visits of the supervisor are periodic and cannot compensate for incompetence on the part of the men on the job.

In public relations too the contacts of the field party with landowners and leaseholders have not always been on a basis which would promote friendly feeling and the best interests of the company for whom the geophysical survey was being conducted. This phase of negligence has been covered very well in Mr. R. W. Dudley's excellent paper on "Public Relations in Geophysical Prospecting" which was read at the regional meeting of the Society of Exploration Geophysicists in Dallas on November 18, 1949. I recommend to you Mr. Dudley's paper.

The failure of geophysical surveys in the past five years to reach, on average, a satisfactory standard of quality and efficiency has been caused by the acute shortage of suitably trained technical personnel. The increased demand and, consequently, more attractive prices for petroleum and petroleum products and the structure and conditions of taxation in the petroleum industry have made geophysical prospecting seem more attractive than ever to the oil companies. They have been willing and eager to invest large sums out of their profits in exploring for and maintaining their production and reserves. Some companies putting out geophysical parties have been encouraged by the persistent demand and by that very human trait, their own avarice, to put in the field parties for which they did not have adequate personnel and equipment. Such parties have, in many cases, failed to produce data which can be expected to yield a reasonable return on the investment. To insure such expectation the supervisor or interpreter of geophysical work should require that the data be of the highest quality possible and he should be sufficiently familiar with operations that he will know what he can reasonably demand. Such knowledge is best gained at the level of observer and party chief.

Men with suitable educational background are again becoming available. Time and experience will give them the necessary skill and training. The exigencies of supply and demand can be expected, in their own hard way, to take care of inefficiency and incompetence. Laboratories are designing and building in sufficient quantity better and more sensitive equipment. With high quality personnel using the best possible techniques and the best equipment available, seismic prospecting may be expected to advance successfully into the more difficult areas still available for evaluation. It is our duty and our responsibility to see that it does.

Eckhardt, E. A., "Geophysical Activity in 1947," *Geophysics*, Vol. XIII, No. 4, October 1948.

Weatherby, B. B., "The History and Development of Seismic Prospecting," *Geophysics*, Vol. V, No. 3, July 1940.

GEOPHYSICAL ACTIVITY IN 1949*

E. A. ECKHARDT†

GEOPHYSICAL ACTIVITY IN THE OIL INDUSTRY

The trend of geophysical activity during 1949 was away from the United States; whereas, seismograph activity in the United States was down 1.43 per cent from the preceding year, that elsewhere was up 28.85 per cent. Gravity operations in the United States in 1949 were down 31.29 per cent as compared to 1948. Elsewhere the decrease was 14.17 per cent. This report is designed to give a composite picture of the geophysical operations of last year with regard to their magnitude and geographic distribution.

The strong downward trend in evidence for the major part of last year may have obscured the fact that, nevertheless, on a world-wide basis, the geophysical activity of the petroleum industry in 1949 was level with, if not slightly above, that of the preceding year. World-wide seismograph activity was up about 4.76 per cent; whereas, the comparable gravity activity was down a more substantial 24.24 per cent. However, the added cost of the additional seismograph work probably just about offset the amounts saved by the reduction in gravity operations so that the global bill of the industry for its geophysical operations in all probability was substantially the same in 1949 as it was in 1948.

The world distribution of seismograph operations in 1949 is depicted in Figure 1. The United States' share of the total is less than that of the previous year by almost five percentage points. Canada's jump from 5.76 per cent to 9.54 per cent of the world total is, perhaps, the most striking development of the year. Canada gained a major part of what the United States lost. However, the gain in the Eastern Hemisphere from 4.45 per cent in 1948 to 7.53 per cent in 1949 is almost as impressive, and the gain in the share of Europe (1.78 per cent to 4.40 per cent) indicates the most rapid expansion found anywhere.

As shown in Figure 2, gravity operations likewise underwent material changes in their distribution during 1949. The United States' share of the world total dropped from 67.9 per cent in 1948 to 53.4 per cent in 1949. For the same periods, Canada's share increased spectacularly from 5.9 per cent to 12.1 per cent, scoring more than a two-fold increase. South America just about maintained its proportion, but the Eastern Hemisphere operations rose robustly from 11.5 per cent to 19.8 per cent.

The distribution of seismograph activity in the United States in 1949, shown

* Report of the Committee on Geophysical Activity of the Society of Exploration Geophysicists. The members of this committee are A. A. Brant, Herbert Hoover, Jr., D. C. Skeels and E. A. Eckhardt, Chairman. Presented at the Chicago Meeting of the Society, April 25, 1950. Manuscript received by the Editor April 10, 1950.

† Gulf Research & Development Company, Pittsburgh, Pa.

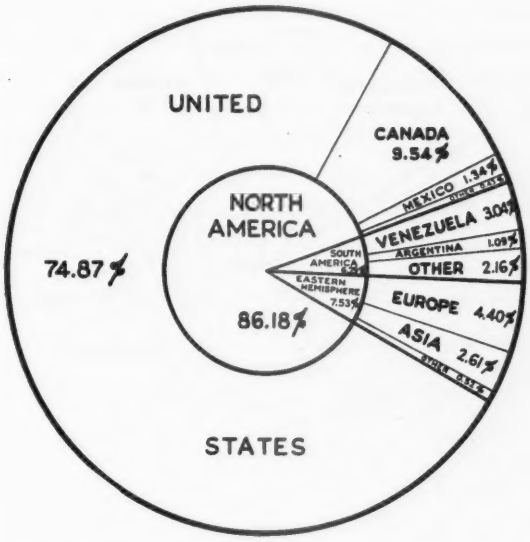

FIG. 1. World distribution of seismograph activity in 1949.

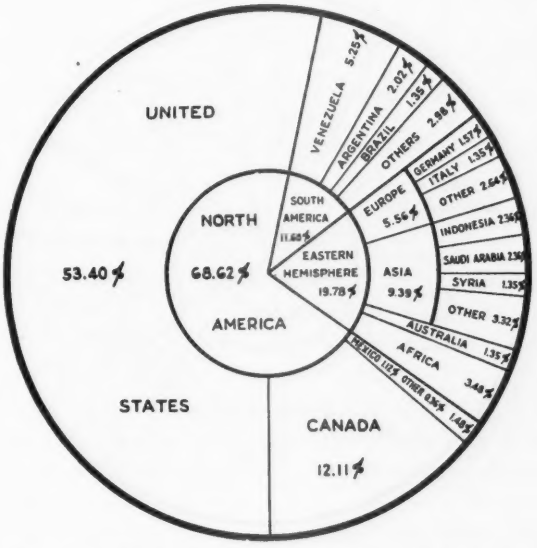

FIG. 2. World distribution of gravimeter activity in 1949.

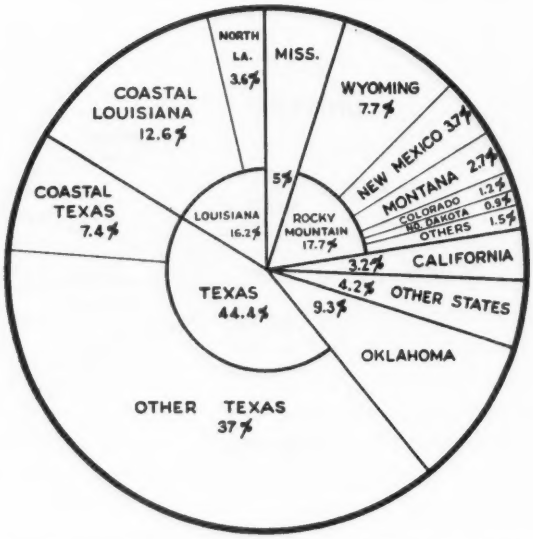

FIG. 3. Distribution of 1949 seismograph operations in the United States.

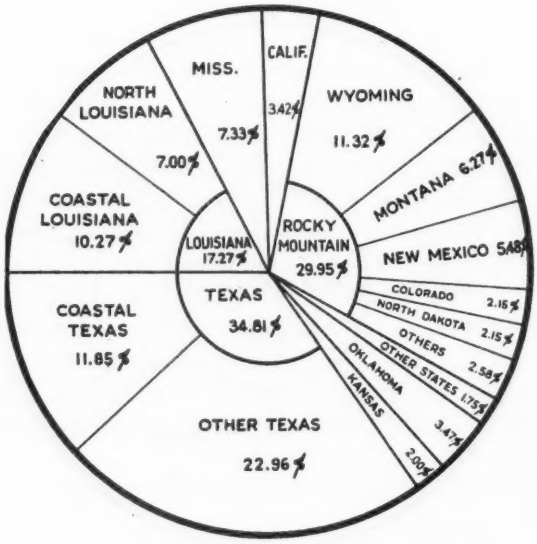

FIG. 4. Distribution of 1949 gravimeter operations in the United States.

in Figure 3, was very much like that of the preceding year. It is worthy of note however that, although the total of such work last year was slightly reduced, the State of Texas achieved a minute increase and, as for some years back increased its share of the total. The Rocky Mountain States also improved their relative position. In Louisiana the reduction came almost entirely from a sharp progressive reduction of off-shore operations during the year.

The relative distribution of gravity work done in the United States in 1949 is shown in Figure 4. In 1948, Texas and Louisiana accounted for 62 per cent of all gravity work in the United States. In 1949, the share of these States was

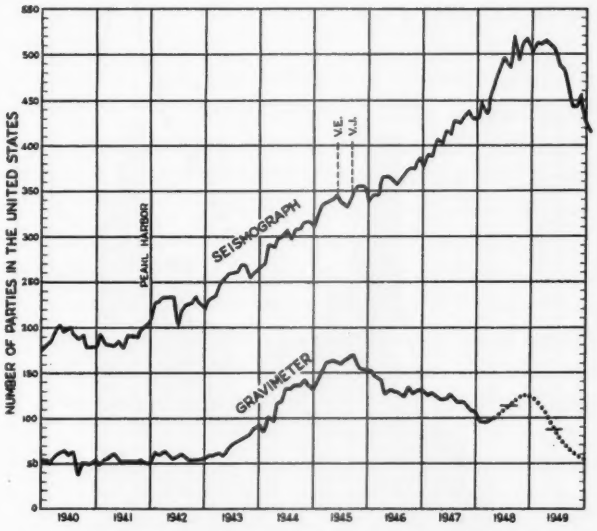

FIG. 5. Monthly variation in seismograph and gravimeter crew months in the United States.

down sharply to 52.08 per cent. These States therefore appear to have borne the brunt of the 31.29 per cent reduction in the total of gravity work done in the United States in 1949 as compared to 1948. The Rocky Mountain States bounced up to 29.95 per cent of the total, but this accomplishment resulted from merely maintaining the crew-months of gravity work at substantially the same level as the year before.

Magnetometer operations during the year were appreciable in magnitude for both ground and air surveys and widespread geographically. Unfortunately, the data available are too sketchy to justify conclusions as to magnitude of total activity or as to trends.

The month-by-month variation in the number of seismograph and gravimeter parties in the United States over the past ten years is shown in Figure 5. While the legend for the cordinates of this Figure is "Number of Parties," a more accurate statement would be "Crew (or Party) Months." The graph shows the

number of seismograph parties at the end of 1949 to have been 427. In a very recent publication, this number was given as 365, a substantially lower figure. This discrepancy caused some concern until it was discovered that the published breakdown included no crews for North Texas. According to the records on which the report here presented is based, there were 54 crews in the overlooked area in December, 1949. This accounts for all but a small part of the difference.

As was the case a year ago, the gravity figures for 1949 have not been available on a month-by-month basis for all areas. The only figures available were the crew-

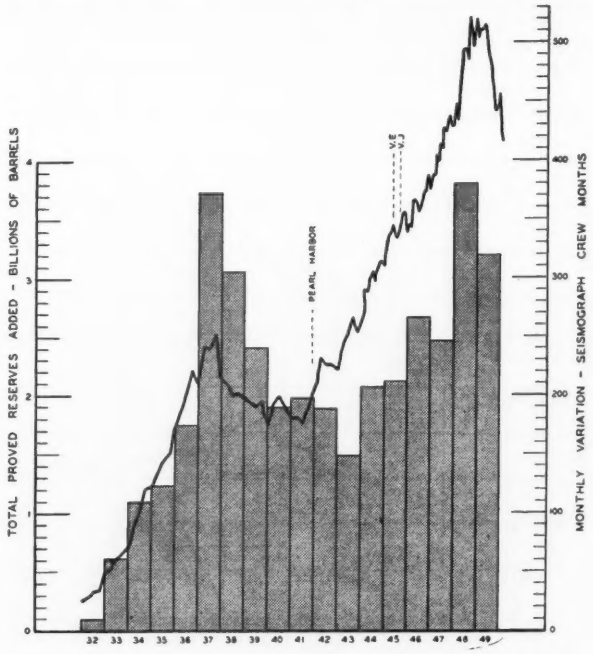

FIG. 6. Comparison of discoveries and seismograph activity in the United States.

months for the entire year. This permitted the computation of the average number of crews employed during the year, which average is indicated by the horizontal dashes on the chart. The dotted curve was judiciously drawn through the averages for the year. On the basis of the crew months reported for the last two years, gravimeter activity in the United States in 1949, was down 31.3 per cent from the year before, to the lowest level of almost seven years.

In the entire history of the industry, discoveries of oil in excess of three billion barrels have been made in the U. S. in only five years, 1929, 1937, 1938, 1948 and 1949. It is to be noted that none of these were war years. While the addition to net reserves was greatest in 1937, the quantity of oil discovered was a maximum in 1948. Last year was the third best discovery year the industry has experienced. The success of exploration during the past two years has no doubt given rise to

a more comfortable feeling about the adequacy of future supply which, together with other factors, has contributed to a relaxing of the exploration effort.

For a parallel to the precipitous drop in seismograph operations, which took place last year in the U. S., one has to go back twelve years to 1937. Figure 6 is presented to show this and the relationship between annual discoveries of crude oil and the concurrent volume of seismograph operations. Discoveries in part replace the oil which has been produced and in part provide net additions to the remaining reserves. It is quite obvious that there is a strong correlation between seismograph operations and discoveries. The closeness of the correlation is especially striking since other very important factors very decidedly affect the magnitude of the discoveries. For example, not a barrel of oil will be discovered if no exploratory drilling is done.

In considering the implications of Figure 6, it is well to remember that at any time that discoveries are substantially larger than necessary to satisfy current needs, the urgency for further exploration will naturally diminish. This is nothing but a manifestation of the law of supply and demand which, despite the efforts of the New and Fair Deals to mutilate, degenerate, emaciate, eviscerate, repeal or ignore it, still demonstrates its validity on the American scene. Since geophysical operations represent the advance guard of the exploration forces, they are the first to encounter changes in climate. However, the full utilization of seismograph surveys is accomplished in a period of years rather than of months and therefore seismograph surveys will continue to contribute to discoveries for some years after they have been completed. Figure 6 reflects all these factors to a remarkable degree.

Figure 6 shows one more thing worth pondering. The number of seismograph parties operating in the U. S. at the peak of the forties was more than two times as great as the number at the peak of the thirties. The oil discovered, however, was not twice as great. No doubt the law of diminishing returns had an important influence here. Oil is an exhaustible resource. As the total of oil consumed and added to known reserves is increased, the amount remaining to be discovered is correspondingly decreased. The ease of future discovery is probably directly proportional to the amount which remains to be found. The cost will rise as the remainder falls. This is probably true regardless of the present efficiency and the probable improvement in the techniques employed in exploration. These will undoubtedly considerably ameliorate the rise in costs. It is improbable that they will prevent it.

It is important to note that Figure 6 covers only operations in the U. S., the most heavily prospected area in the world. It is almost certain that the U. S. has discovered a greater fraction of its ultimate production than any other area of great potential. This needs to be considered in determining how to apportion the exploration dollars between domestic and foreign areas.

U.S. wells have produced more than half of their all-time output of crude oil during the last 13 years. More than half of the natural gas saved and marketed

from them has been produced during the last 11 years. Although these periods included the war years, an inspection of the tabulated annual production data affords no clue as to when the war began, when it ended or, in fact, that there was any war. This indicates the recent pace of the industry and is reasonable evidence of sturdy growth which, save for minor adjustments, may be confidently projected into the future.

Barring a material decrease in the U.S. standard of living, all social and economic factors indicate a rising trend in the future demand for petroleum prod-

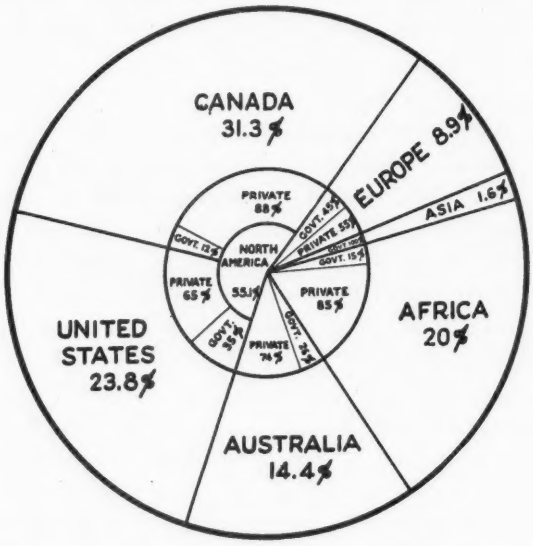

FIG. 7. World distribution of geophysical operations in mining by areas in 1949.

ucts. Since the discoveries of the past two years have been exceptionally large, they may not reasonably be expected to set a new pattern. Rising production will inexorably require an increased volume of geophysical surveys. It is probable that the recent peaks of activity will be surpassed in the very near future.

GEOPHYSICAL ACTIVITY IN THE MINING INDUSTRY

The world-wide expenditures made by the mining industry for its geophysical work appear to have been larger in 1949 than they were in 1948 by some 38 per cent. Since this is only the second year for which such data have been compiled on the present basis, it is possible that a part of this increase may arise from the fact that the 1949 data are somewhat more complete, but there has undoubtedly been a substantial increase.

The reported expenditures for research and development were almost 41 per cent greater in 1949 than in 1948. Of the funds so spent, the United States contributed a full half (52.7 per cent) and Canada about a third. Africa and Aus-

tralia, though their geophysical surveys were substantial in scope, devoted relatively minor sums to research. Almost half (45 per cent) of the research work was concerned with electrical methods. Geochemical, magnetic and seismic methods ranked next in that order and between them accounted for 42 per cent of the research effort. These figures do not include research at any of the Univerisites, which in the aggregate may have been appreciable.

The distribution by major geographic units of the geophysical operations of the mining business during 1949 is shown graphically by Figure 7. Canada still

FIG. 8. World distribution of geophysical work in mining, by methods in 1949.

ranks first with 31.3 per cent of the total, but its position is considerably less dominant than it was the previous year. The United States is a stronger second with 23.8 per cent. The greatest change has been in Africa, which has improved its position by an almost threefold increase from 7.3 per cent to 20.0 per cent. The share of Europe also increased strikingly from 3.9 per cent to 8.9 per cent. Australia's share was about the same in both years. No data were available from Russia and none are included for South America.

Since for each country or continent shown in Figure 7 the work done involved a variety of methods, it was necessary to reduce the work data to money equivalents in order to arrive at a total for any country which would determine the size of the sector assignable to it.

Comparison of Figure 7 with the corresponding one for 1948 indicates a trend away from government support except in the case of Canada, where a slight change in the opposite direction occurred.

The distribution by method of the 1949 geophysical work of mining interests

is shown in Figure 8. Magnetic methods still exceed others in the extent of their use although by a somewhat reduced margin. The decrease is found entirely in the use of ground magnetic methods. The airborne magnetometer showed a moderate gain over 1948.

The use of electrical methods appears to have declined somewhat. The decline has been principally in the employment of self-potential and electromagnetic methods. Use of the resistivity method, on the other hand, has countered the trend, and has increased.

Opportunities for discovering surface mineralizations are diminishing year by year. As time goes on, industry will be increasingly dependent on other indices to localize its prospecting efforts. It is reasonable to expect that, as was true in the oil industry, geophysical methods will prove to be the most effective and economical means for fulfilling this need and that foresight in this respect is likely to be well rewarded.

The data and related information which made the preparation of this report possible came from many sources and were gathered with great care. It is a pleasure to acknowledge the assistance of my associates in the committee and the help given me by members of my staff and others in the collection and compilation of the data and in the preparation of this report.

GEOPHYSICAL DATA ON THE NORTH CAROLINA COASTAL PLAIN*

D. C. SKEELS†

ABSTRACT

Results are given of surveys conducted in 1944–1946 by the Esso Standard Oil Company in northeastern North Carolina, and extending into the southeast corner of Virginia. Gravitational, magnetic, refraction and reflection surveys were made. The gravity and magnetic maps indicate a basement of complex composition, with a grain approximately north-south. The refraction data show the regional eastward dip of a high velocity layer, which in the western part of the area is identified as crystalline basement, but which in the eastern part is believed to be a limestone in the Lower Cretaceous. The reflection survey of Pamlico Sound shows regional east dip with a number of noses plunging east and northeast, and some possible faults but no closed structures.

Beginning in the early part of 1944, and ending in the early part of 1947, the Esso Standard Oil Company conducted an exploration venture on the Coastal Plain of northeastern North Carolina, (extending into southeastern Virginia). The exploration work included surface geology, gravity and magnetic surveys, a regional refraction survey, detailed seismic reflection surveys, and finally the drilling of two dry holes. The results of the geological work and the drilling have been published in a recent paper by Walter B. Spangler (1950) in the Bulletin of the American Association of Petroleum Geologists. The purpose of the present paper is to give the results of the geophysical surveys, in the thought that they may be of interest to the geophysical profession as a case history, and to the geologists as throwing additional light on the geological structure of the Atlantic Coastal Plain.

GRAVITY SURVEY

It was realized at the beginning of the program that the regional tectonic setting made it unlikely that anticlinal features of sufficient relief to be detected by gravity or magnetic methods would be present on the Coastal Plain. It was thought possible, however, that there might be faults present which could be revealed by these methods, especially since very little was known of the subsurface geology. This hope proved illusory; while there are some minor features on the maps which could be interpreted as fault indications, they could also be caused by density and magnetic variations in the basement rocks, and this interpretation is considered the more likely. While these surveys, therefore, gave little information regarding possible structural traps, they did give some information on the regional slope of the basement surface, and they gave a considerable amount of information on the make-up and tectonics of the basement itself, which should be of interest to students of igneous rocks.

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† Standard Oil Co. (N. J.), New York, New York.

Gravity meter observations were made at intervals of about one-half mile on nearly all of the available roads, and some observations were made off the roads, in accessible places, as along the coast. A limited number of observations were made in the shallow waters of Pamlico Sound, by using a tripod and boats. An elevation correction factor of 0.07 mg/ft. determined from detailed profiles over topographic features, was used to reduce the data to sea level.

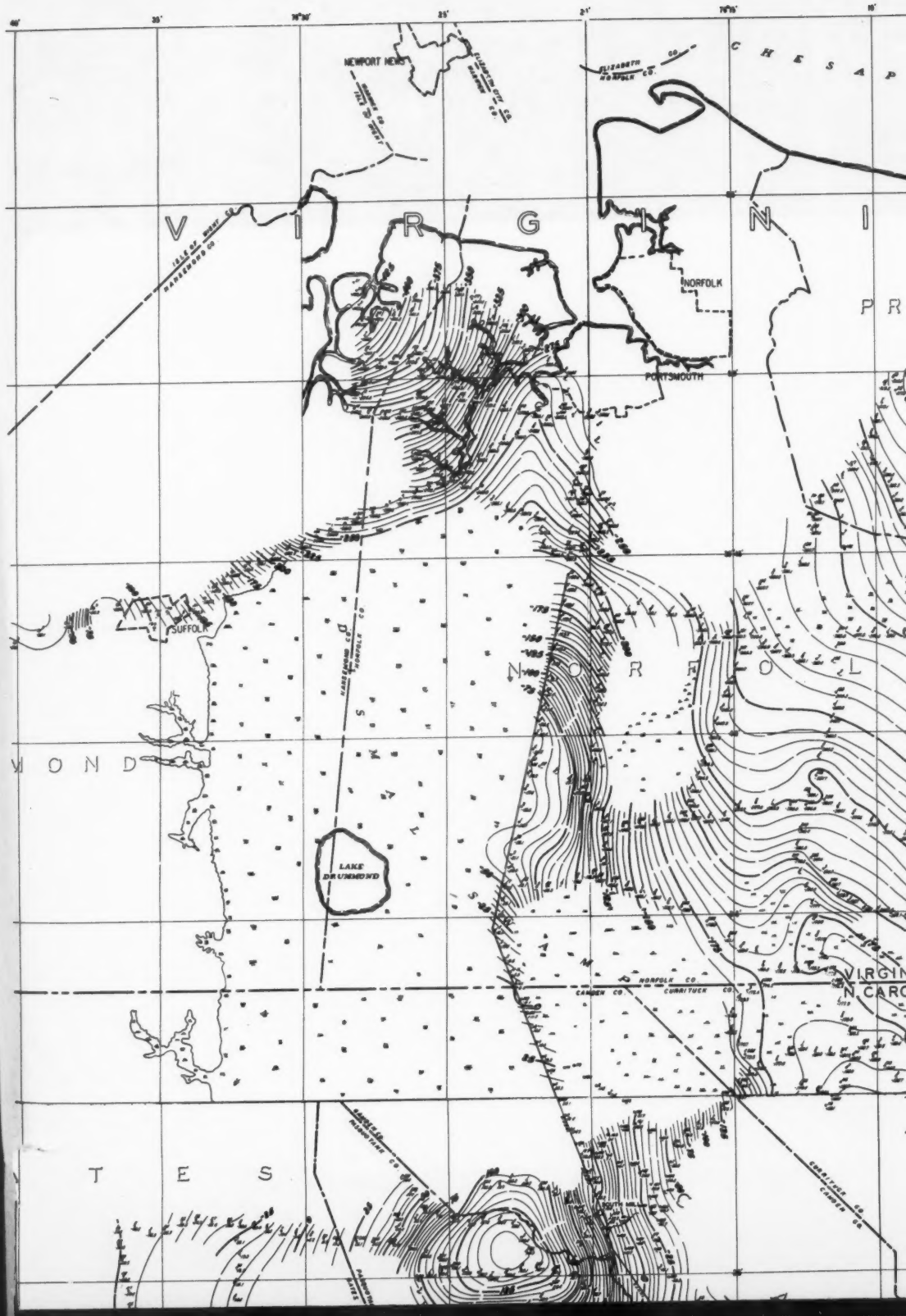
In order to preserve as much detail as possible, the gravity data are shown on two sheets, Plate I for the northern half of the area and Plate II for the southern half. The contour interval is five gravity units (or one-half milligal). The values shown are for the Bouguer anomaly, on the International Formula. By tying in to numerous pendulum stations in the area it was possible to place the data on the absolute gravity system.

Because of the inaccessibility of many parts of the area the data are necessarily patchy, and the regional features are not apparent at first glance. A little study shows, however, that there is a large regional low in the southern part of the area, northwest of Pamlico Sound, and a regional high in the northern and western parts of the area. A number of local closures and noses occur on this regional high, particularly in the western half of the northern area. In the southeastern half of the southern sheet gravity is increasing toward the southeast, indicating that another high probably lies not far off Cape Hatteras.

Quantitative as well as qualitative considerations indicate that most of the gravity anomalies shown on this map must be due to variations in density in the pre-Cretaceous basement. Many of the features are too large to be due to basement relief, even if we were permitted to assume a highly irregular pre-Cretaceous surface. The prominent circular high northwest of Elizabeth City, for example, is in an area where the depth to the basement, from refraction data, is only 2,400 feet; there is hardly room for a structure large enough to produce this 15-milligal anomaly. Moreover, in the Cape Hatteras area the basement is falling in the direction in which gravity is rising; here the gravity is clearly due to something within the basement complex.

Figure 1 is a residual gravity map of the northern area. Even these residual anomalies are of considerable amplitude, and look more like effects of basement lithology than anything else. On the evidence of the gravity, as well as the magnetic results, it seems probable that the basement under this part of the Coastal Plain is similar to that which is exposed in the Piedmont belt of North Carolina and Virginia. The Virginia state map shows a great variety of igneous and metamorphic rocks in the Piedmont, ranging from acid to basic, forming narrow outcrops elongated in a direction slightly east of north. As most of these rock masses can be assumed to have considerable vertical extent, and, from their lithology, considerable variation in density, it can be supposed that some of them would give rise to gravity anomalies of considerable amplitude, such as we see in the area covered by our map.

Against such a complex background of effects due to basement lithology, it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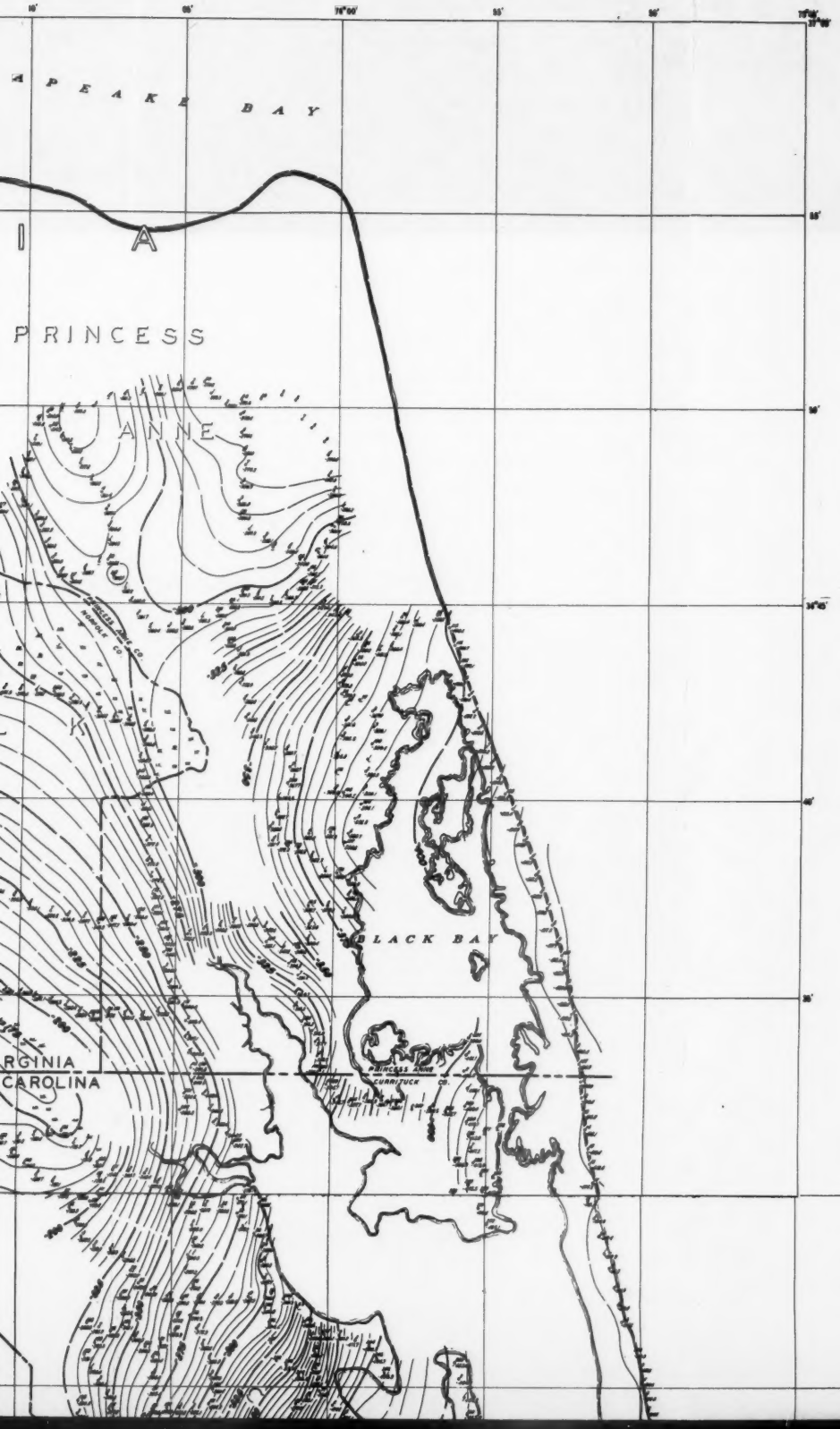
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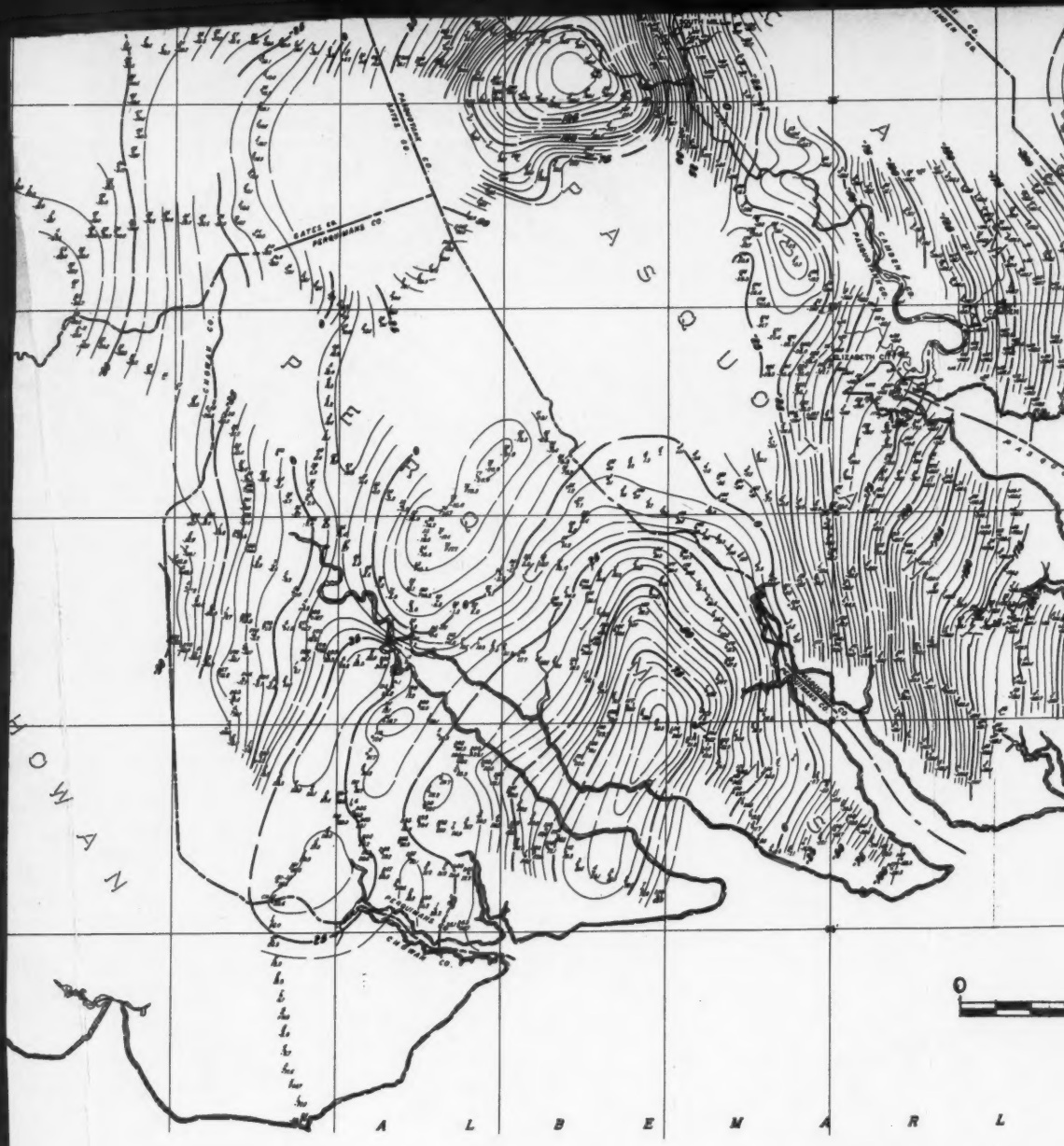
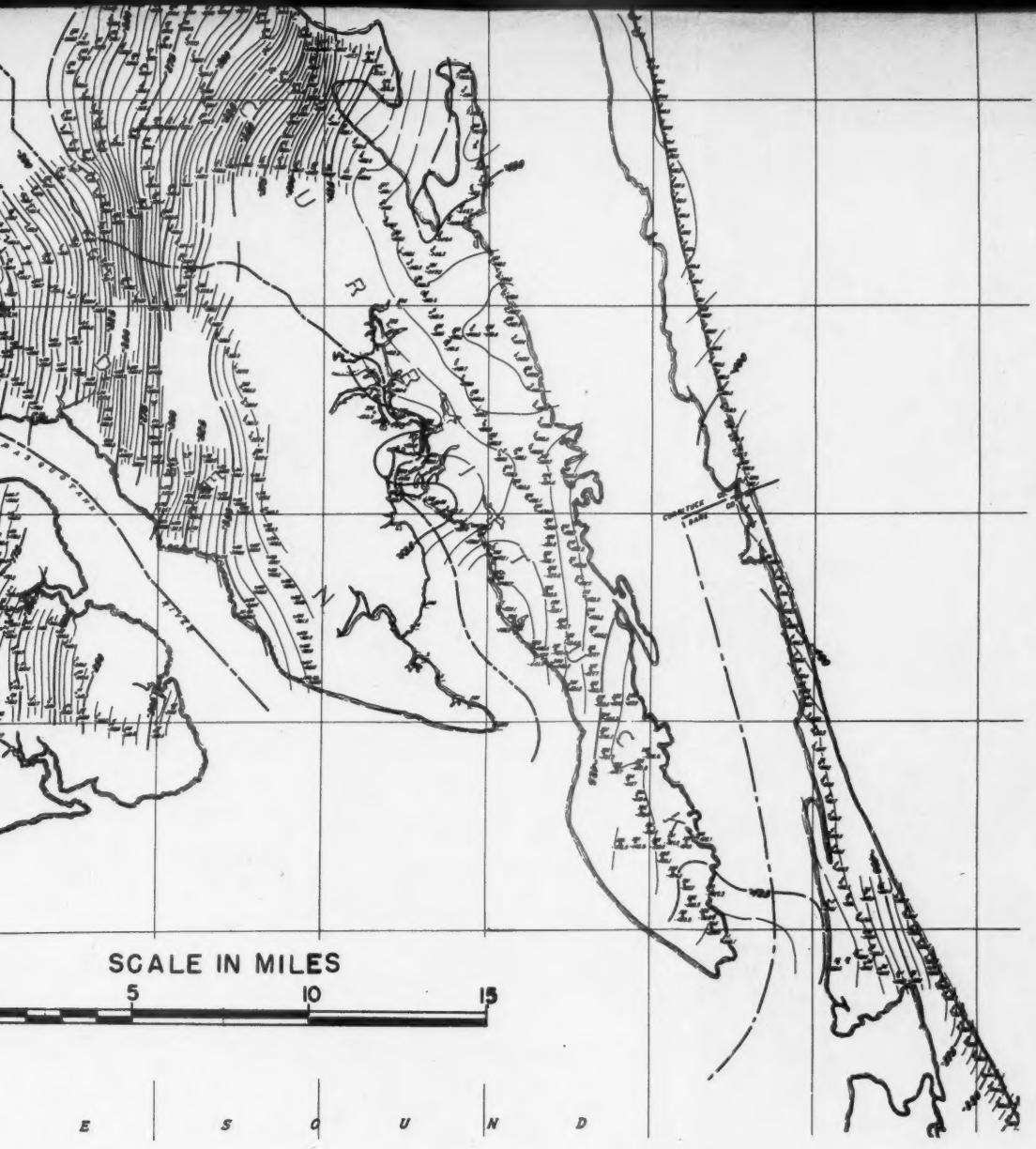


PLATE I. Bouguer anomalies of gravity, north of Albemarle Sou



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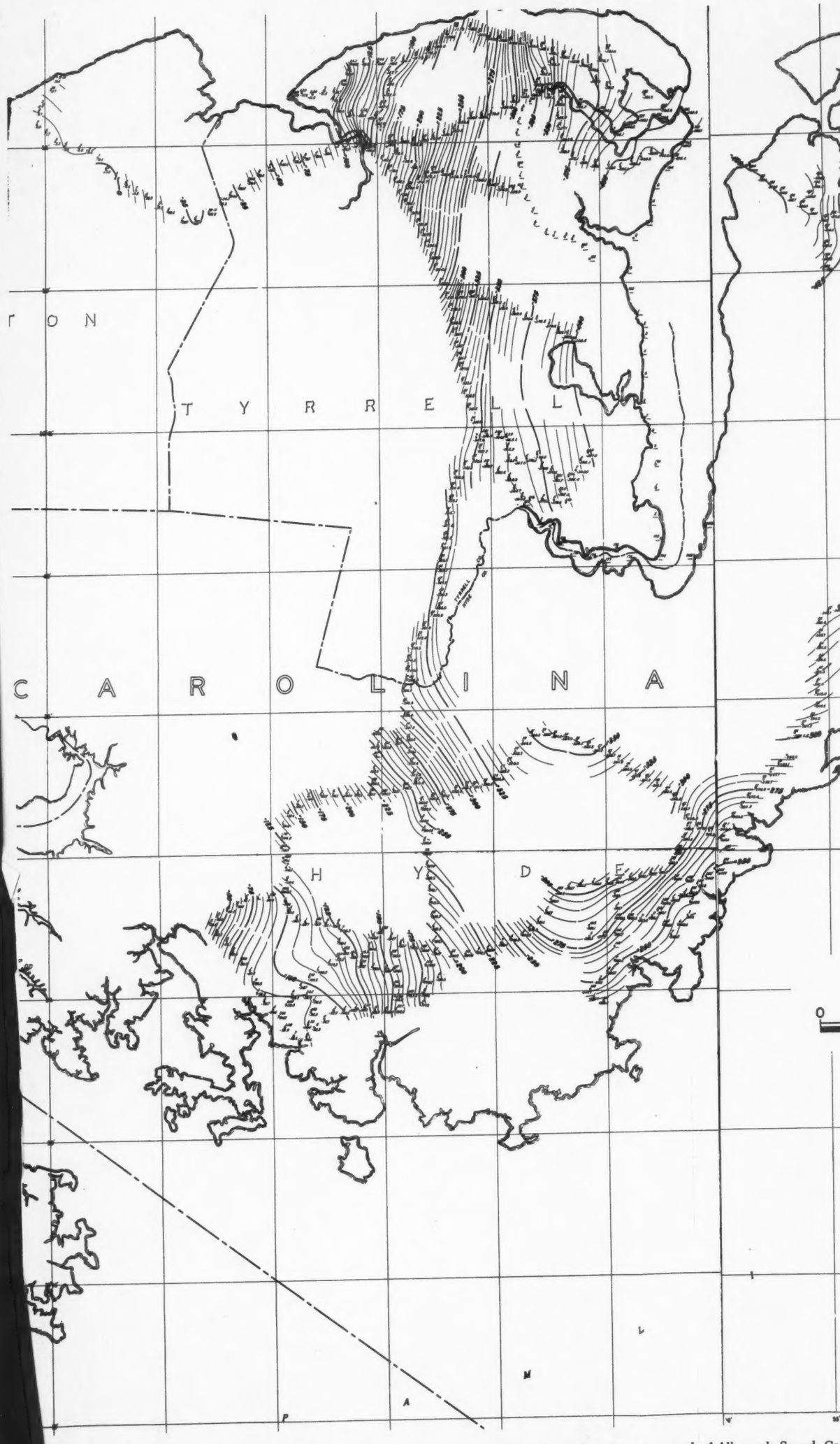
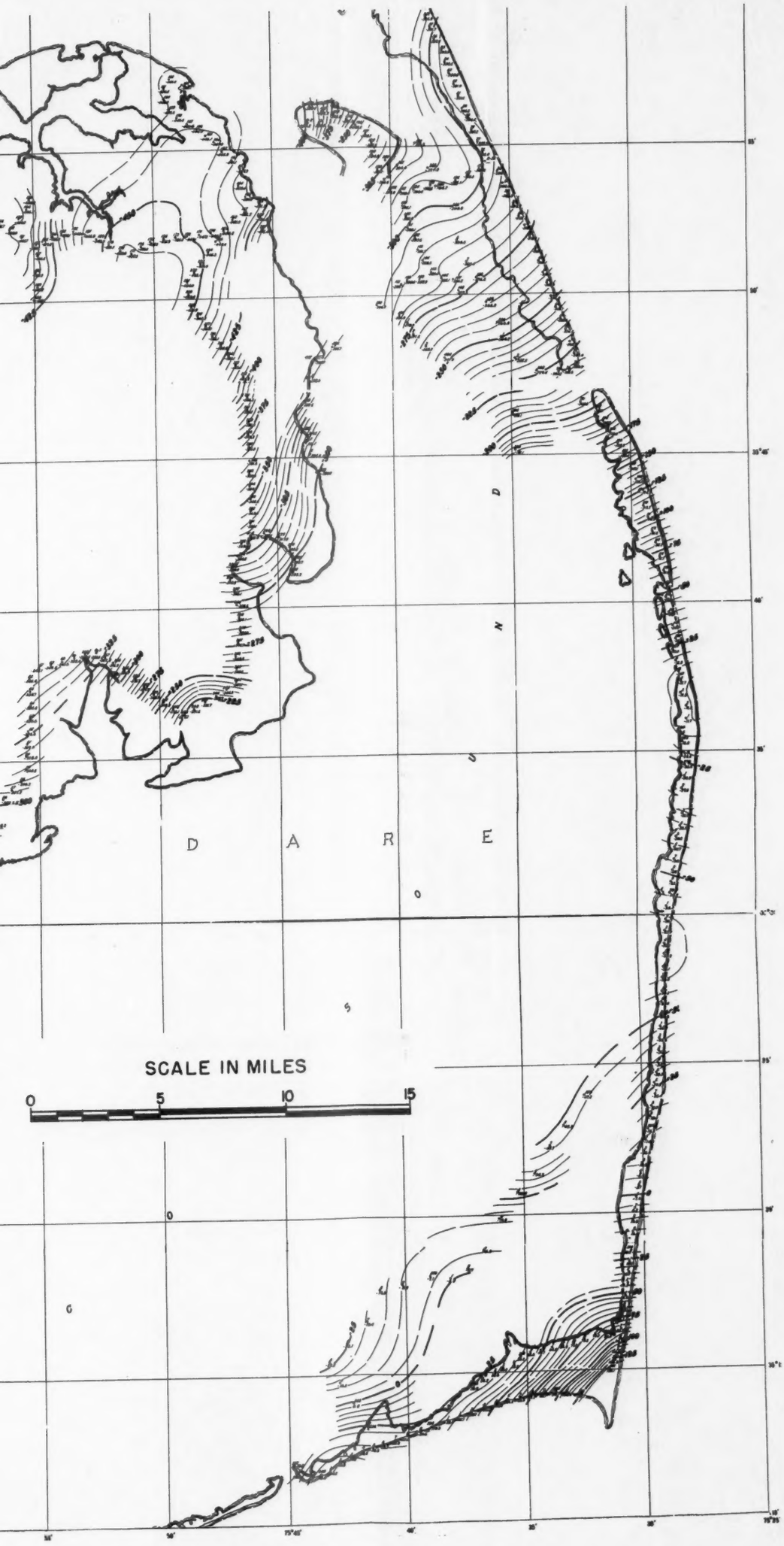


PLATE II. Bouguer anomalies of gravity, south of Albemarle Sound. Co



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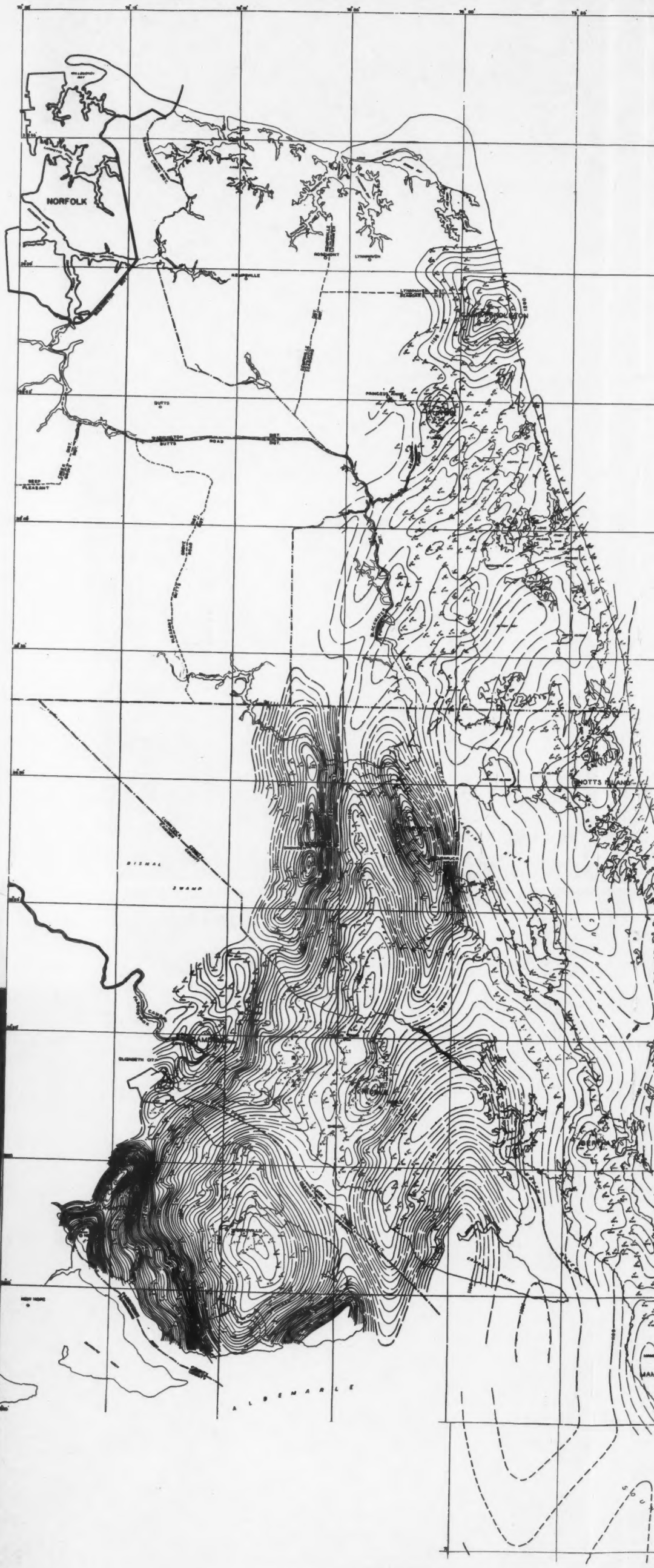
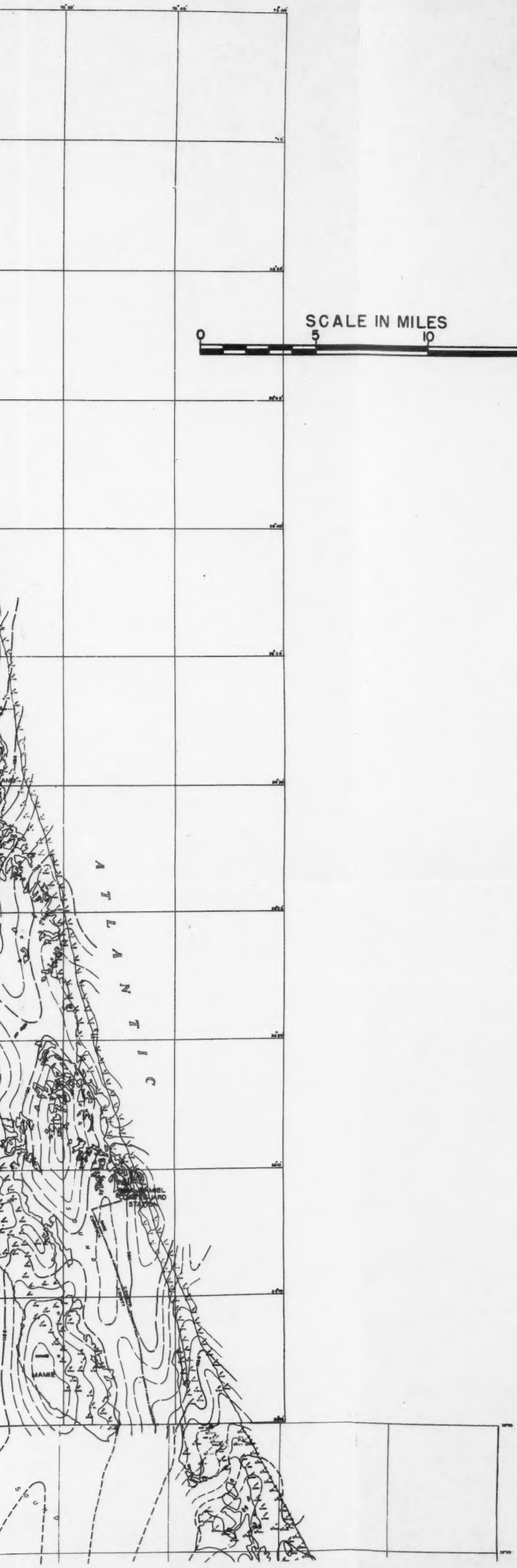


PLATE III. Anomalies of vertical magnetic intensity, north of Albemarle S



emarle Sound. Contour interval ten gammas.

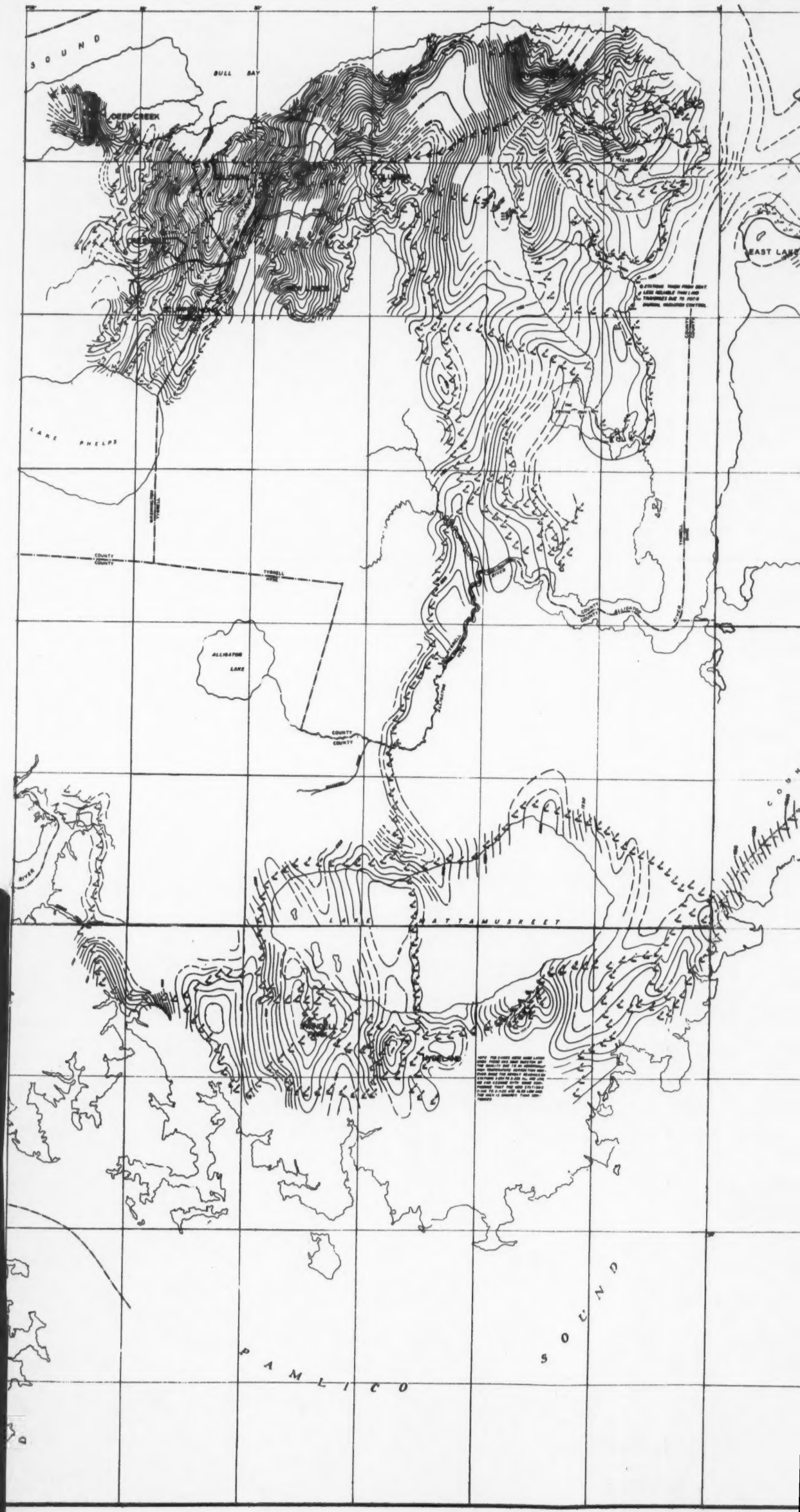
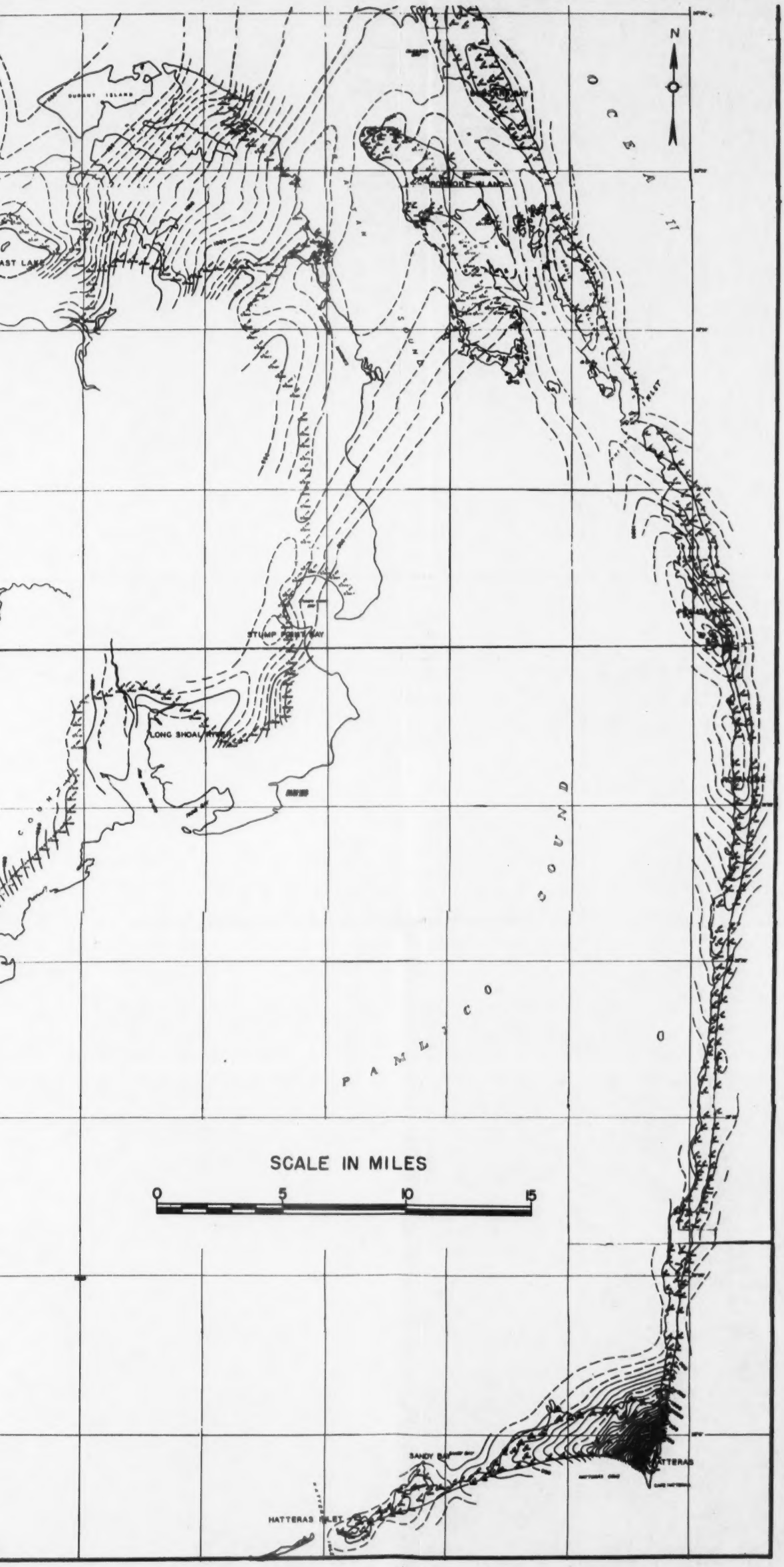


PLATE IV. Anomalies of vertical magnetic intensity, south of Al



uth of Albemarle Sound. Contour interval ten gammas.

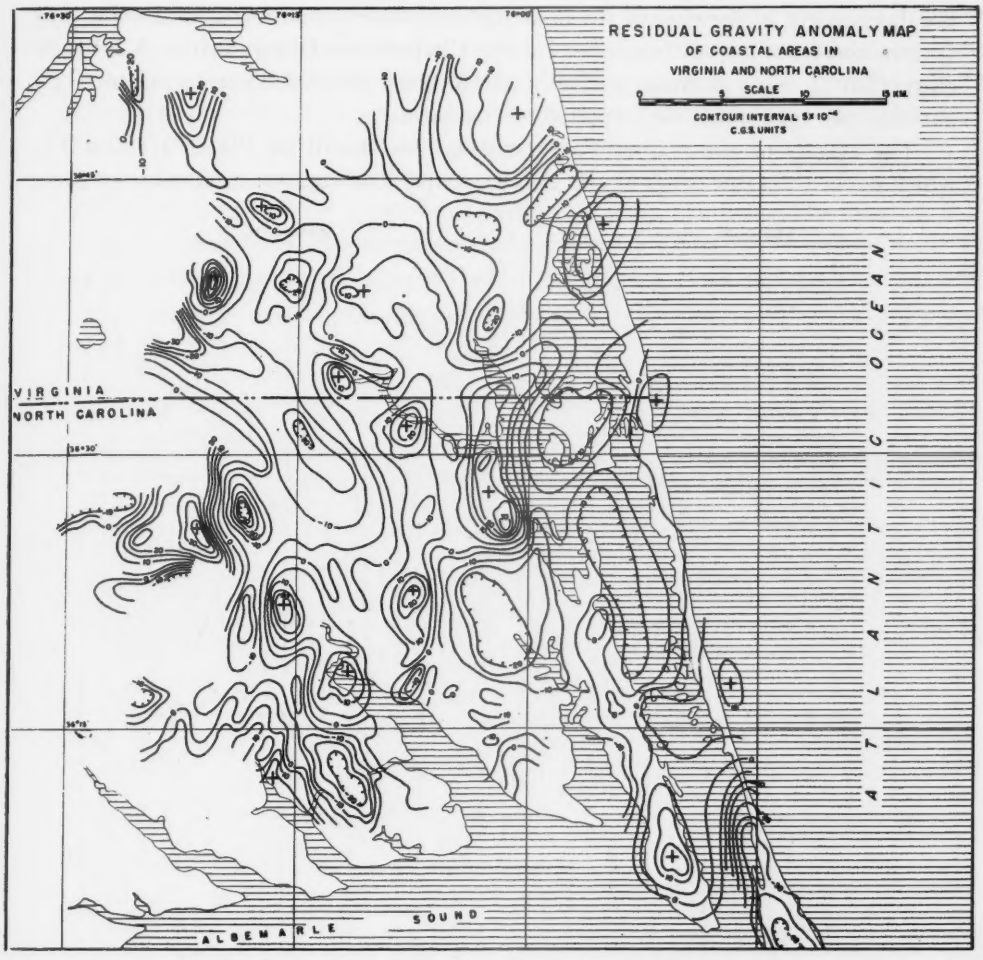


FIG. 1. Residual gravity north of Albemarle Sound. Contour interval five units (one-half milligal).

would be extremely difficult to distinguish an anomaly which might be the result of moderate folding or faulting in the sediments, or of moderate relief on the basement surface. Anomalies due to these causes may be present, but their existence would be very difficult to prove.

MAGNETIC SURVEY

About 2,500 stations were observed with an Askania Vertical Magnetic Field Balance, with a sensitivity of 20 gammas per scale division. Most of the stations were reached by car, but some foot traverses were made, and along the Alligator River some stations were reached by a skiff powered by an outboard motor. Diurnal corrections were made by returning to base stations several times during

the day, except in the case of the boat stations, where the diurnal correction was determined from curves furnished by the Cheltenham Observatory. A latitude correction of −9.3 gammas per mile north and a longitude correction of −3.5 gammas per mile south were applied to the data.

The results of the magnetometer survey are shown on Plates III and IV, which cover the same areas as the gravity maps. The contour interval is 10 gam-

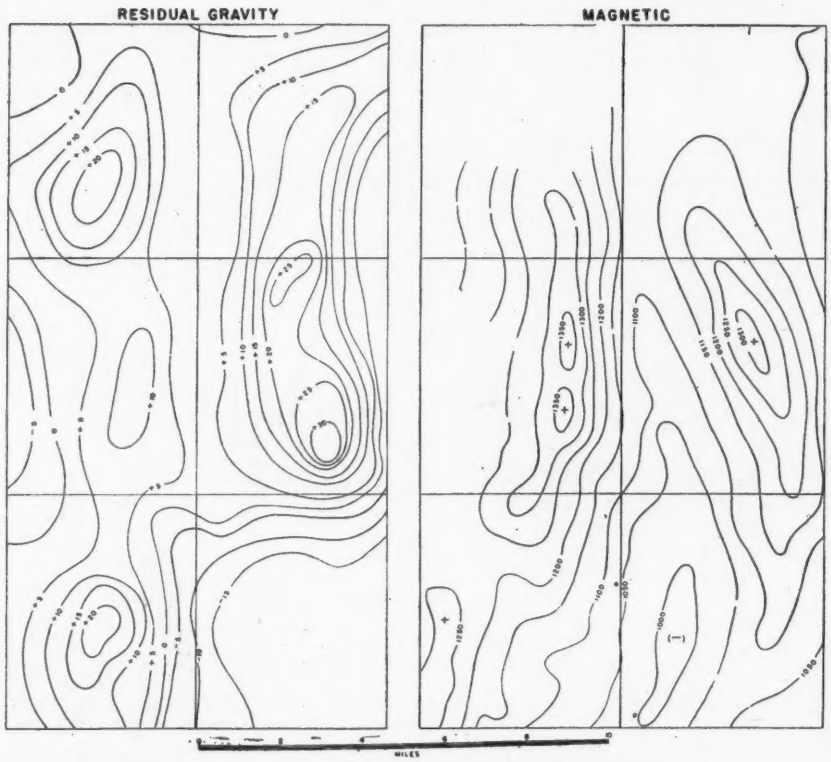


FIG. 2. Magnetic and residual gravity anomalies near Currituck, North Carolina.

mas. There are certain similarities between the gravity and the magnetic maps; there are also some important differences. The magnetic anomalies show the same north-south trend as do most of the gravity features. In the northern section a number of strong, narrow anomalies fall on the east flank of the main gravity high, where in some cases they coincide with relatively minor gravity features. This is illustrated by the two narrow anomalies just south of the Virginia line: on Figure 2 are shown these two anomalies, and for comparison, the *residual* gravity anomalies for the same area. In this case, there is little doubt that the gravity and magnetic effects are caused by the same rock masses. Again, on Cape Hatteras there is a strong resemblance between the two pictures, although neither shows a complete anomaly.

On the other hand, there are localities where the two maps are quite different. This is to be expected, of course, since density variations and magnetic variations in the basement rocks do not necessarily go hand in hand. One notable difference between the two maps is that the magnetic anomalies are more numerous and of narrower width than the gravity anomalies. This can be explained in the following manner; in the first place, the magnetic map tends to accentuate effects from the *upper* part of the basement more than does the gravity map, because the effect varies as the cube instead of the square of the distance; in the second place, the magnetic properties of the igneous rocks seem to be much more

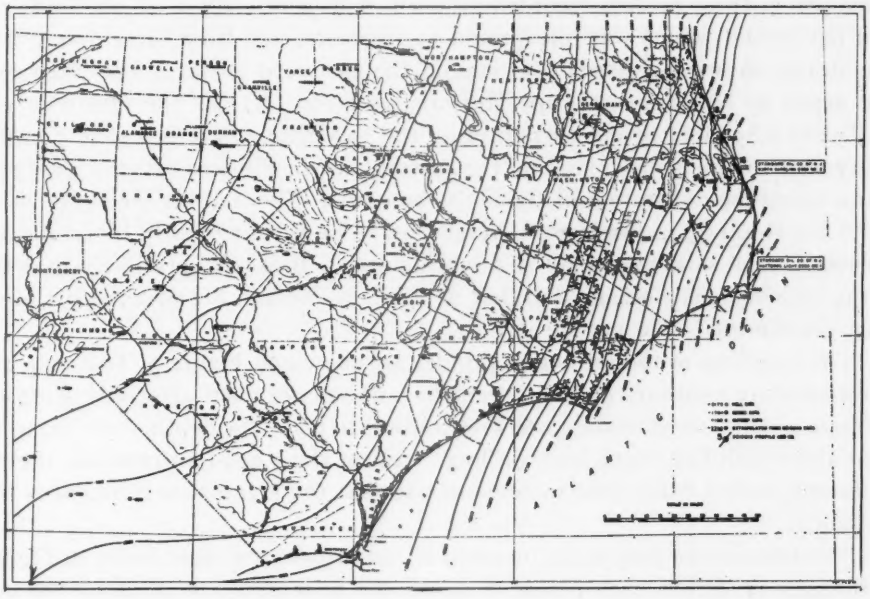


FIG. 3. Map showing location of refraction profiles, with contours on the basement surface from well control and refraction data (extrapolated east of 3,000-foot contour—see text). After Spangler.

variable than does the density; a change of two or three per cent in the magnetite content of a granite could double its magnetic susceptibility, but would have only a negligible effect on its density.

Because effects from the upper part of the basement are accentuated on the magnetic map, we can usually obtain some idea of the basement depth from the width, shape, and amplitude of the magnetic anomalies. Narrow anomalies require a shallow source; broad anomalies are of deep origin if the source is concentrated, but can be of shallow origin if the source is broad. By making certain assumptions regarding the magnetic bodies, Dr. R. J. Watson of The Carter Oil Company made estimates of the depth to the basement surface for anomalies in various parts of the area. These estimates agreed reasonably well with later results from refraction work and drilling.

The magnetic data confirms the indication from the gravity map that the basement under this part of the Coastal Plain is of a complex nature, made up of rocks of contrasting properties, with most of the contacts striking approximately north and south. Lithologically and structurally it seems to be a part of the same geological province as the Piedmont.

REFRACTION SEISMOGRAPH PROFILES

Fifteen refraction profiles were shot on various parts of the Coastal Plain for the purpose of determining the depth to the basement and the regional basement slope. All of these profiles recorded an event with a velocity of 18,000 to 20,000 feet per second, which was interpreted as basement, and from these data a map was drawn showing regional contours on the basement surface. This map gave the depth to basement at Cape Hatteras as 8,200 feet. As the Hatteras well drilled to 9,853 feet before encountering the basement, there is a strong probability that the high speed layer in the eastern part of the area was not basement but a limestone-dolomite well above the basement. The well log shows the interval 8,515 to 9,150, in the Lower Cretaceous, to be predominantly limestone and dolomite, with sand and shale in minor amounts. It seems very likely that this is the high velocity horizon, and that none of the shots in the eastern part of the area encountered true basement.

The locations of the refraction profiles are shown on Figure 3. This map also shows surface contours on the basement surface, obtained after adjusting the refraction depths east of the 3,000-foot contour to make the depth at the Hatteras well agree with the depth from drilling. West of the 3,000-foot contour, there is sufficient control from wells to demonstrate that the high-speed refractor is true basement.

The travel-time graphs for fourteen of the profiles are reproduced in Figures 4 through 17. Below each profile is shown the interpretation made by the geophysical staff of The Carter Oil Company, who used a method combining mathematical calculation and geometrical construction.

It will be noted that in the western part of the area, profiles 1 through 7 show only two layers, the upper with a velocity which varies, in different profiles, from 5,800 feet per second to 7,400 feet per second, and the lower with a velocity of 18,000 to 20,000 feet per second. In the eastern part of the area, profiles 8 through 18 show one or more additional layers with intermediate velocities—see, for example, profile 9.

At the eastern extremity of the area, on the barrier beach, first arrivals from the intermediate velocity layers were not distinct, so that secondary arrivals were used, or velocity values assumed. The depth determinations for these longer profiles are therefore not as accurate as where the basement is shallower. While it is conceivable that this is the source of the 1,650 feet discrepancy in depth to "basement" at the Hatteras well, the explanation already given—refraction off the limestone—seems more likely.

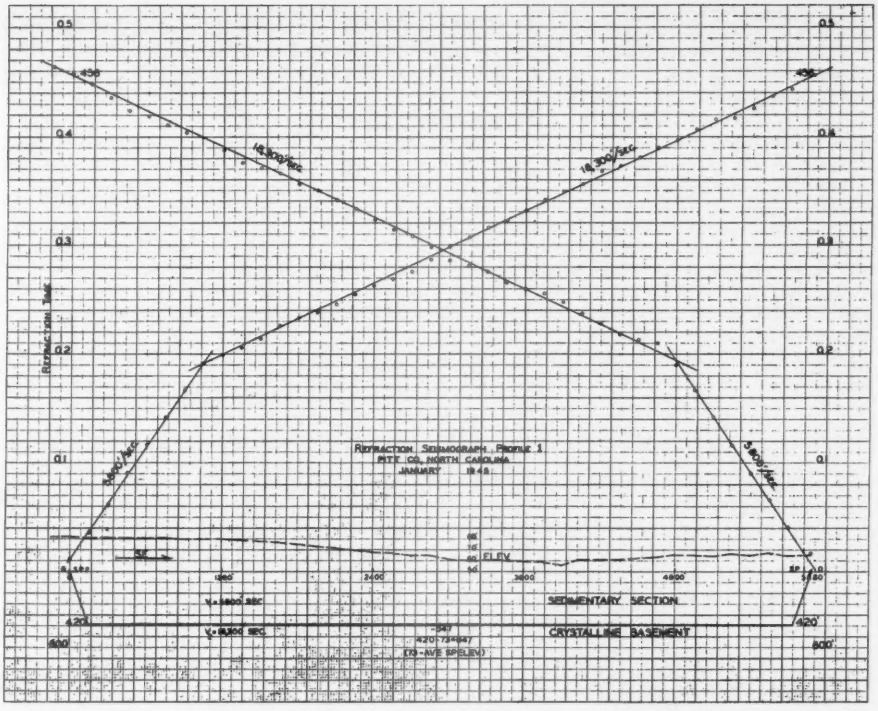


FIG. 4. Refraction profile No. 1.

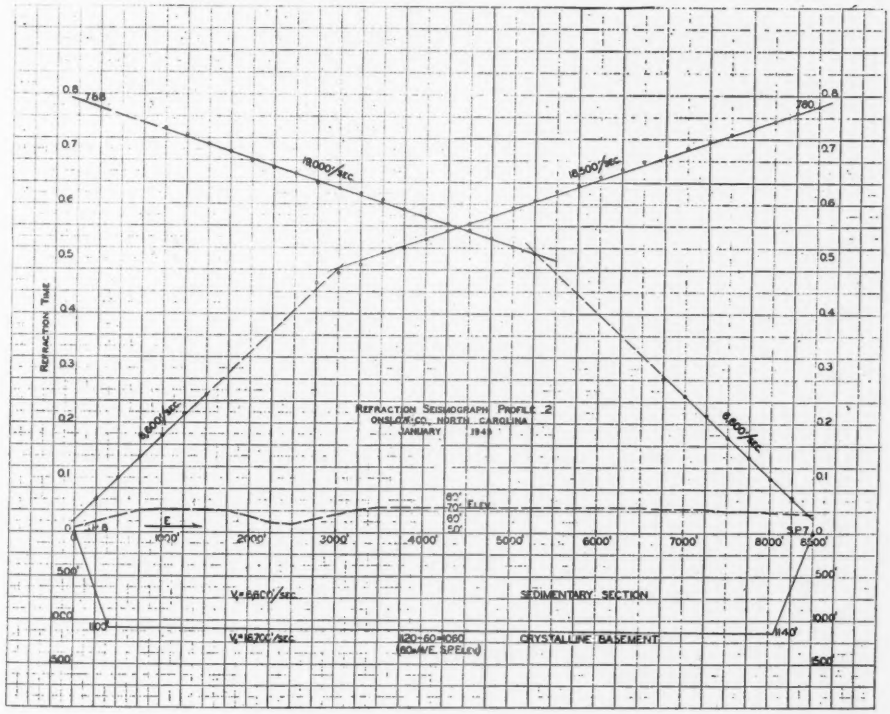


FIG. 5. Refraction profile No. 2.

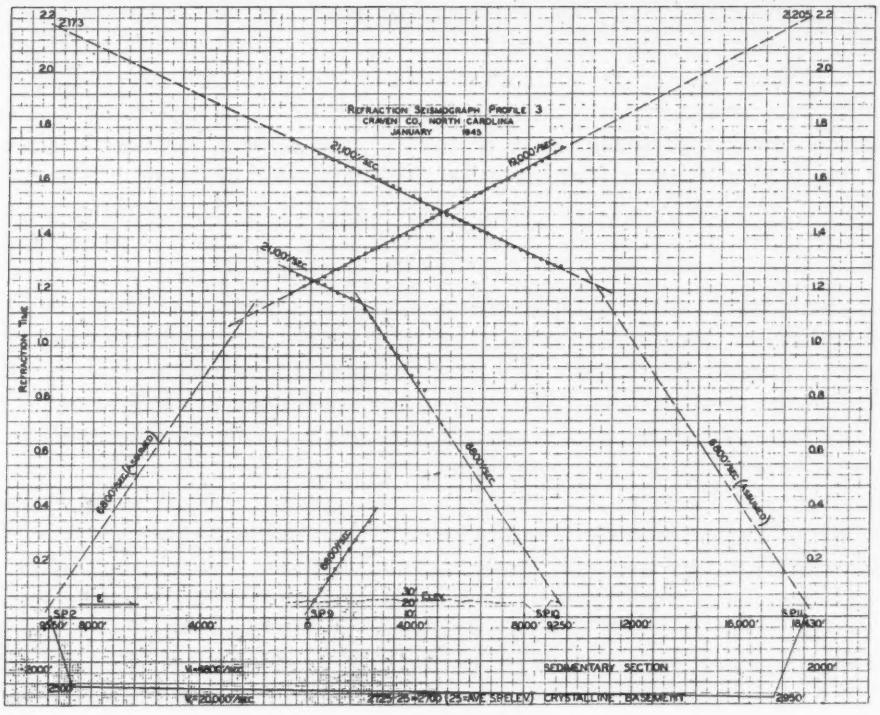
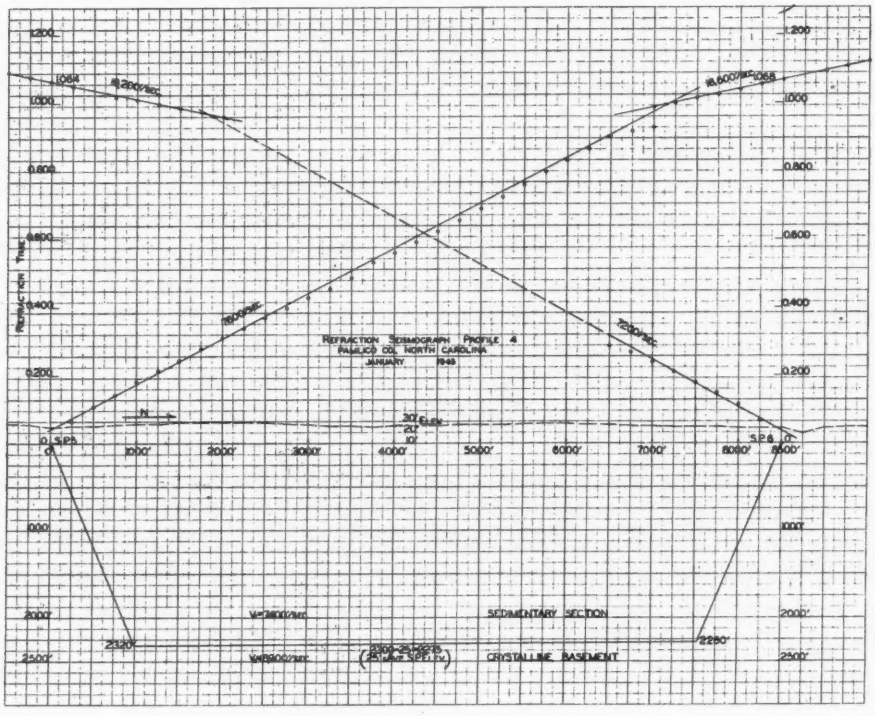


FIG. 6. Refraction profile No. 3.



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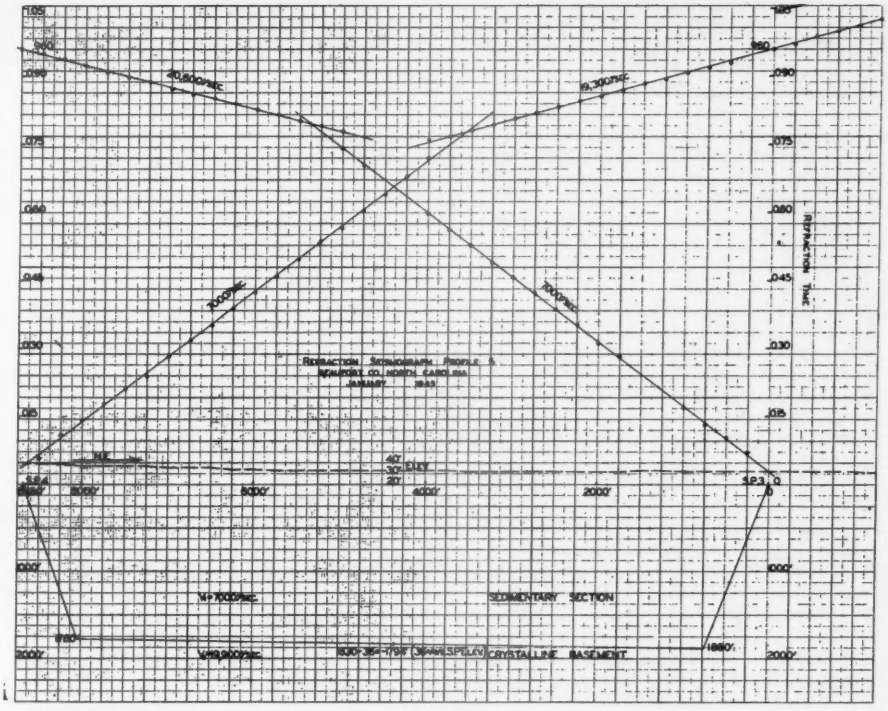


FIG. 8. Refraction profile No. 5.

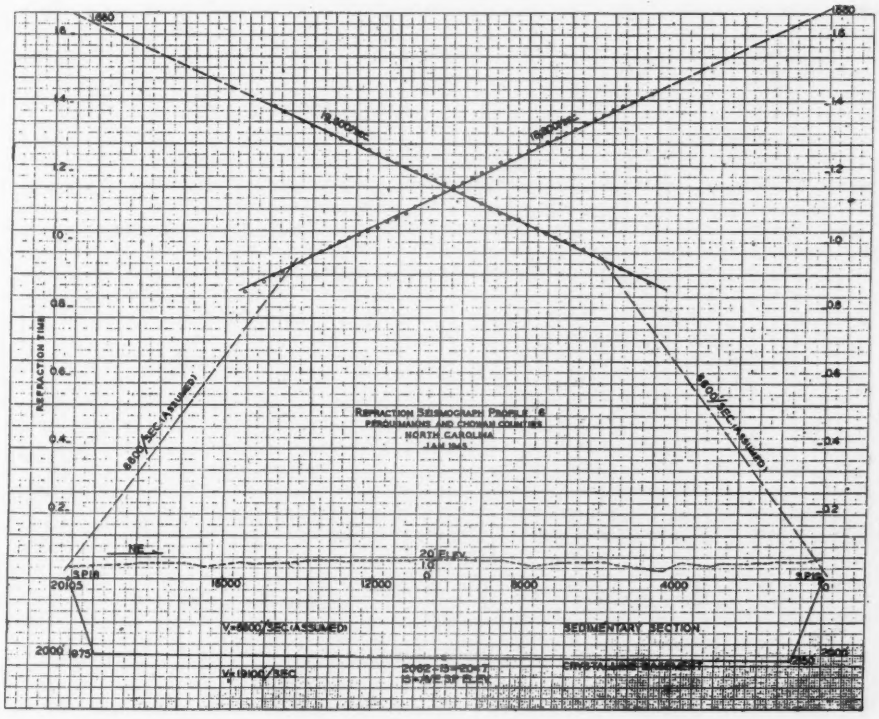


FIG. 9. Refraction profile No. 6.

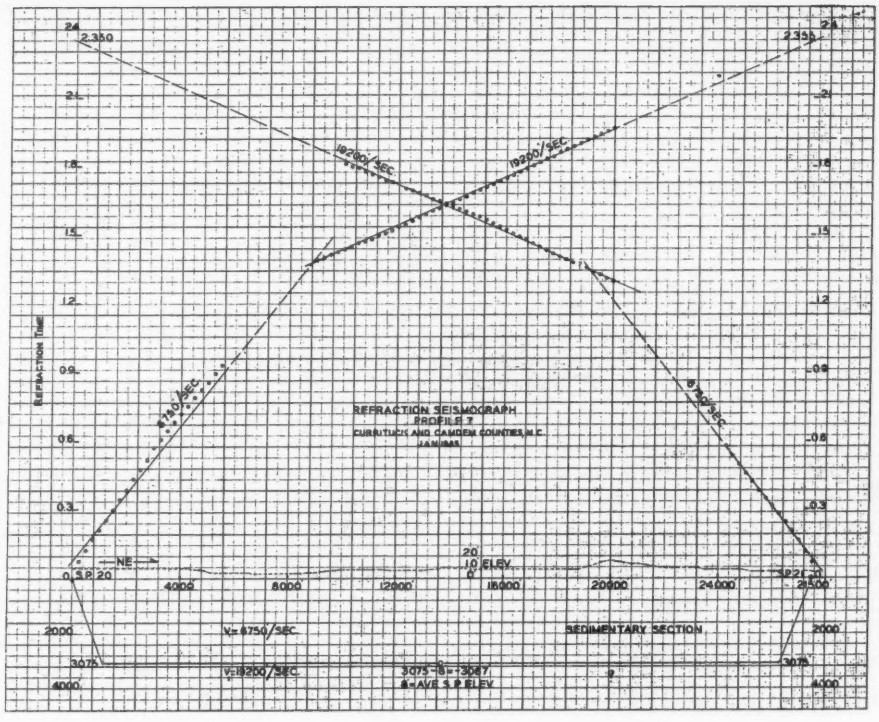


FIG. 10. Refraction profile No. 7.

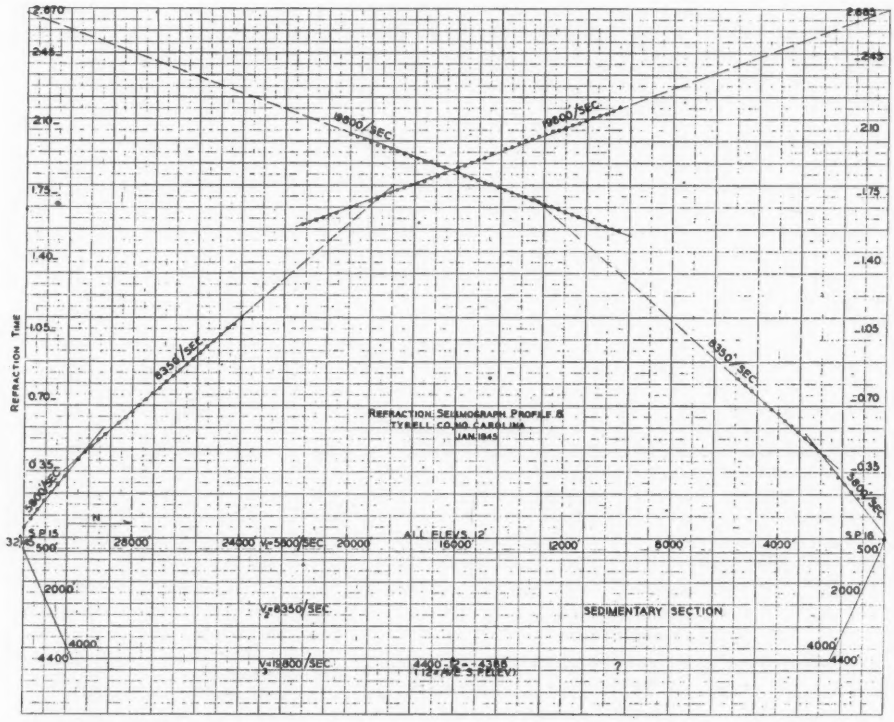


FIG. 11. Refraction profile No. 8.

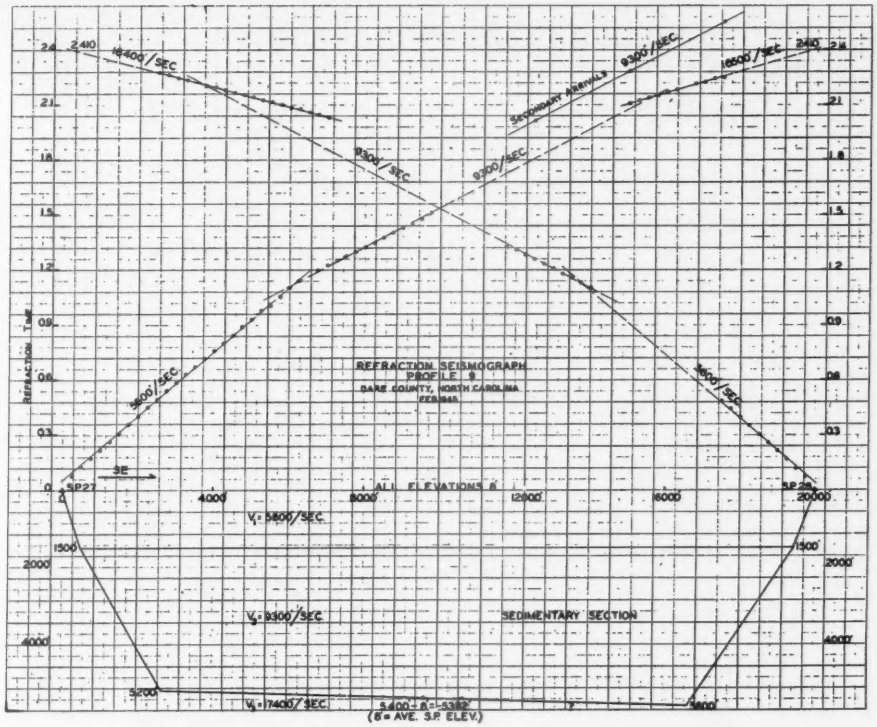
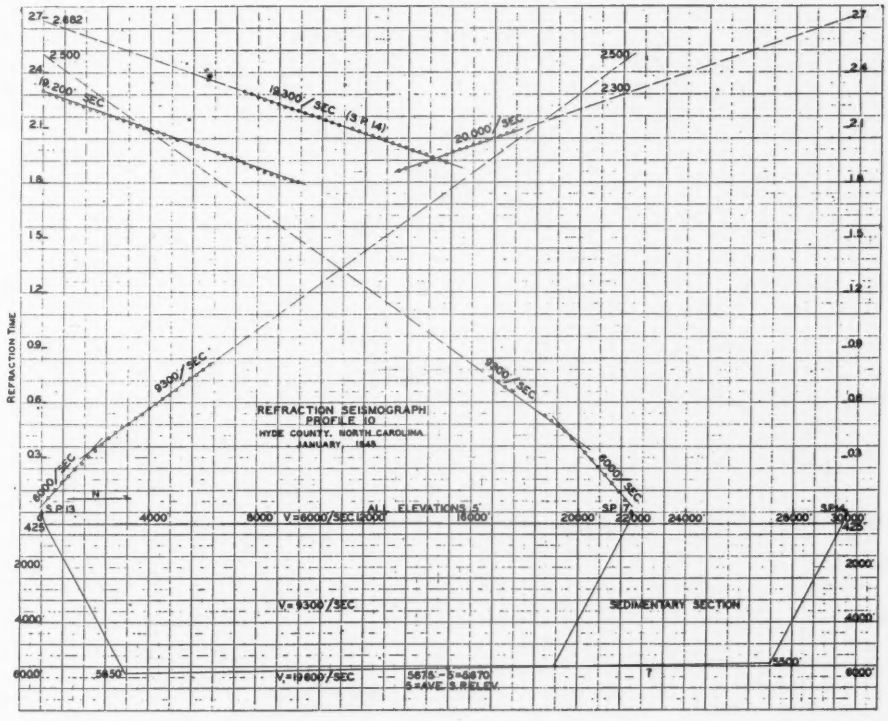


FIG. 12. Refraction profile No. 9.



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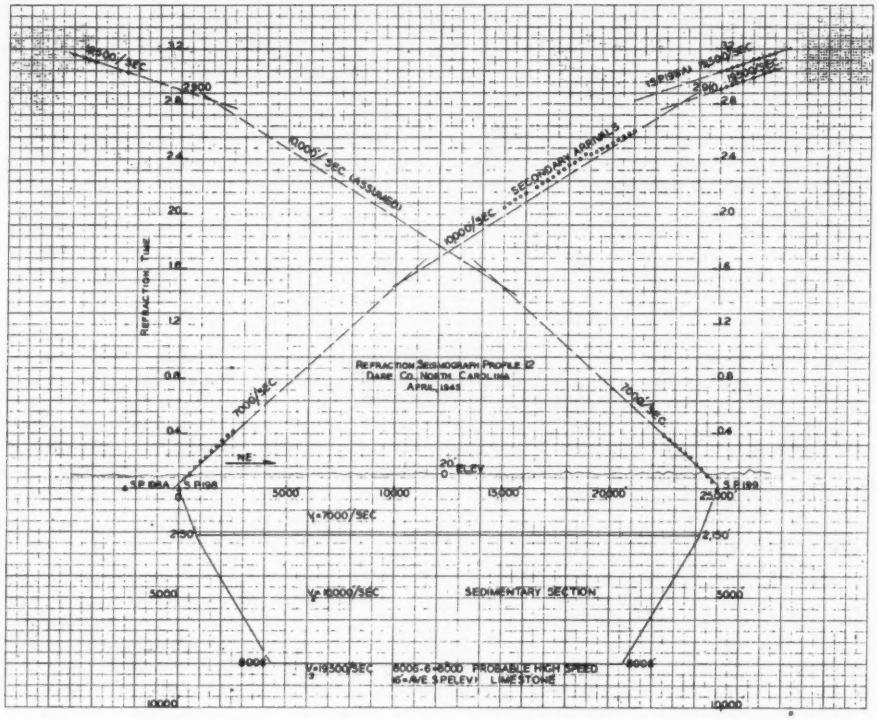

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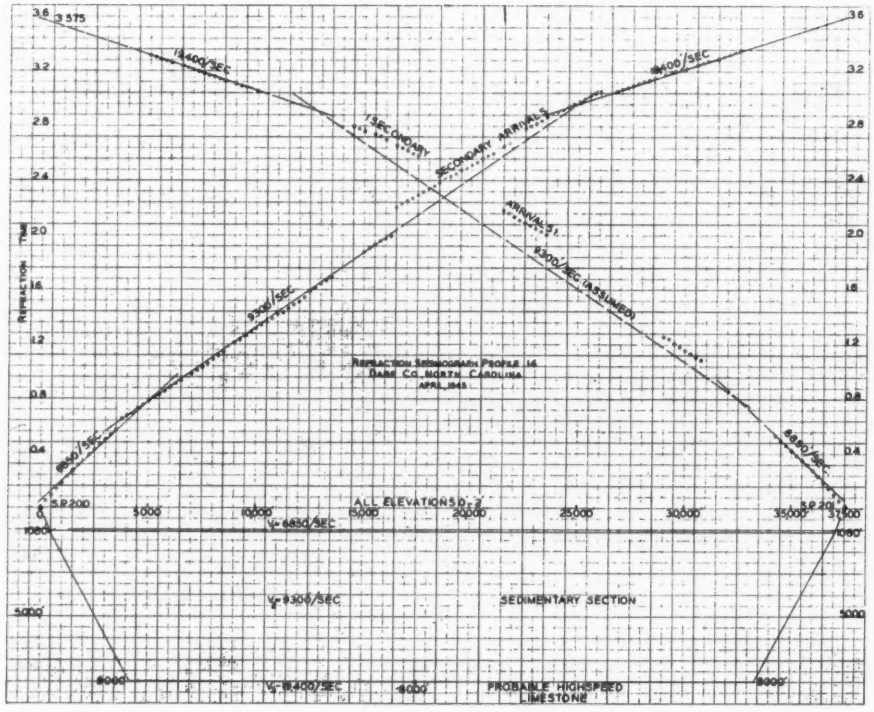

FIG. 15. Refraction profile No. 14.

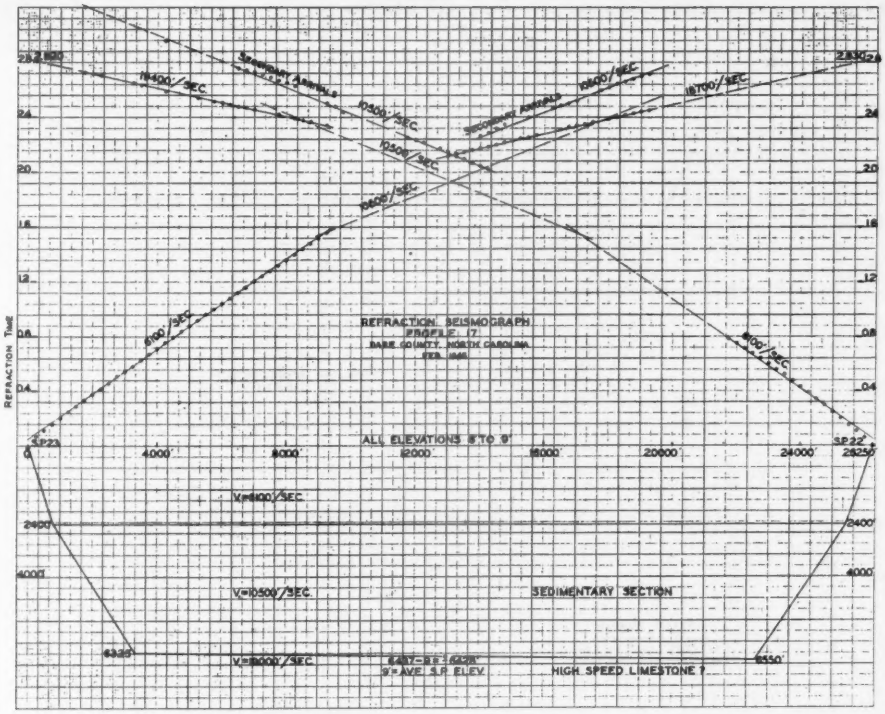

FIG. 16. Refraction profile No. 17.

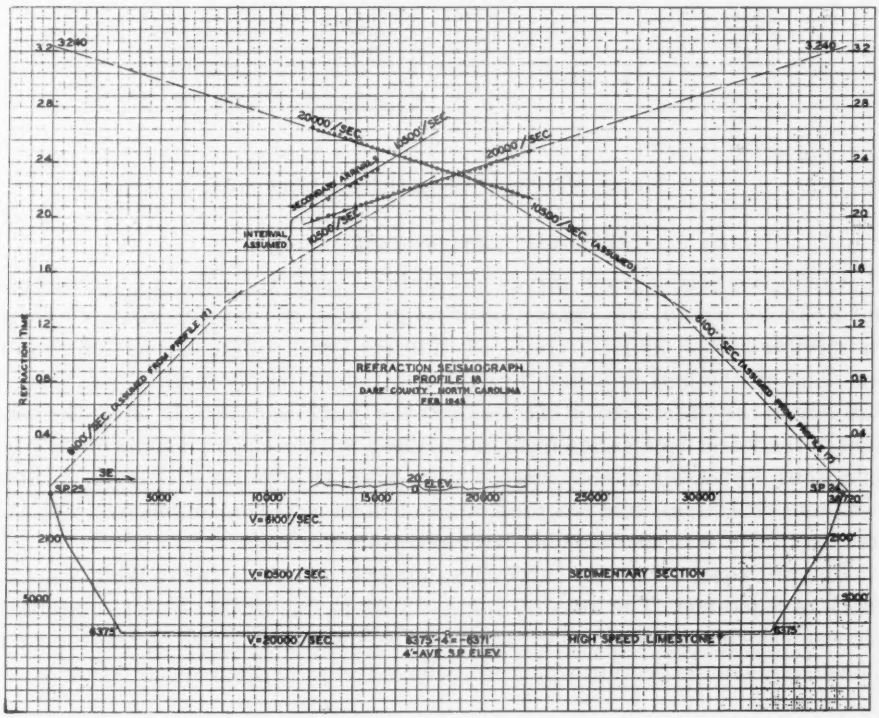

FIG. 17. Refraction profile No. 18.

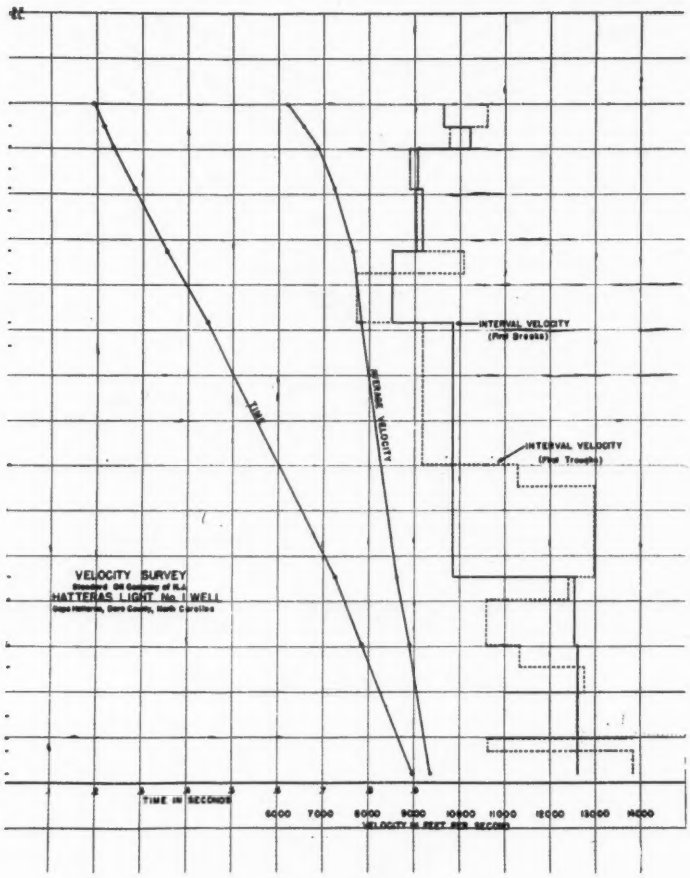

FIG. 18. Velocity survey of Hatteras Light No. 1.

REFLECTION SEISMOGRAPH SURVEY

A reflection seismograph survey of Pamlico Sound, the adjacent barrier beach, and Roanoke Island, was carried on through most of 1945 and 1946, employing the services of two contract crews, at different times. Some correlation shooting was done on the barrier beach, but the continuous profile method was used exclusively in the water area. Reflections on the beach were mostly poor; the reflections in the water area varied from fair to good, with occasional spots of very poor reflections. Reflection quality was usually related to firmness of bottom. Although numerous reflections were recorded, none of them were continuous over any large area, so that it was necessary to carry phantom horizons.

In April 1946, a velocity survey was made of Hatteras Light Well No. 1 to a depth of 8,400 feet. The velocity log is shown as Figure 18. Unfortunately, the deepest velocity determination, at 8,400 feet, was just short of the top of the limestone-dolomite section which we believe to be the high-speed refractor.

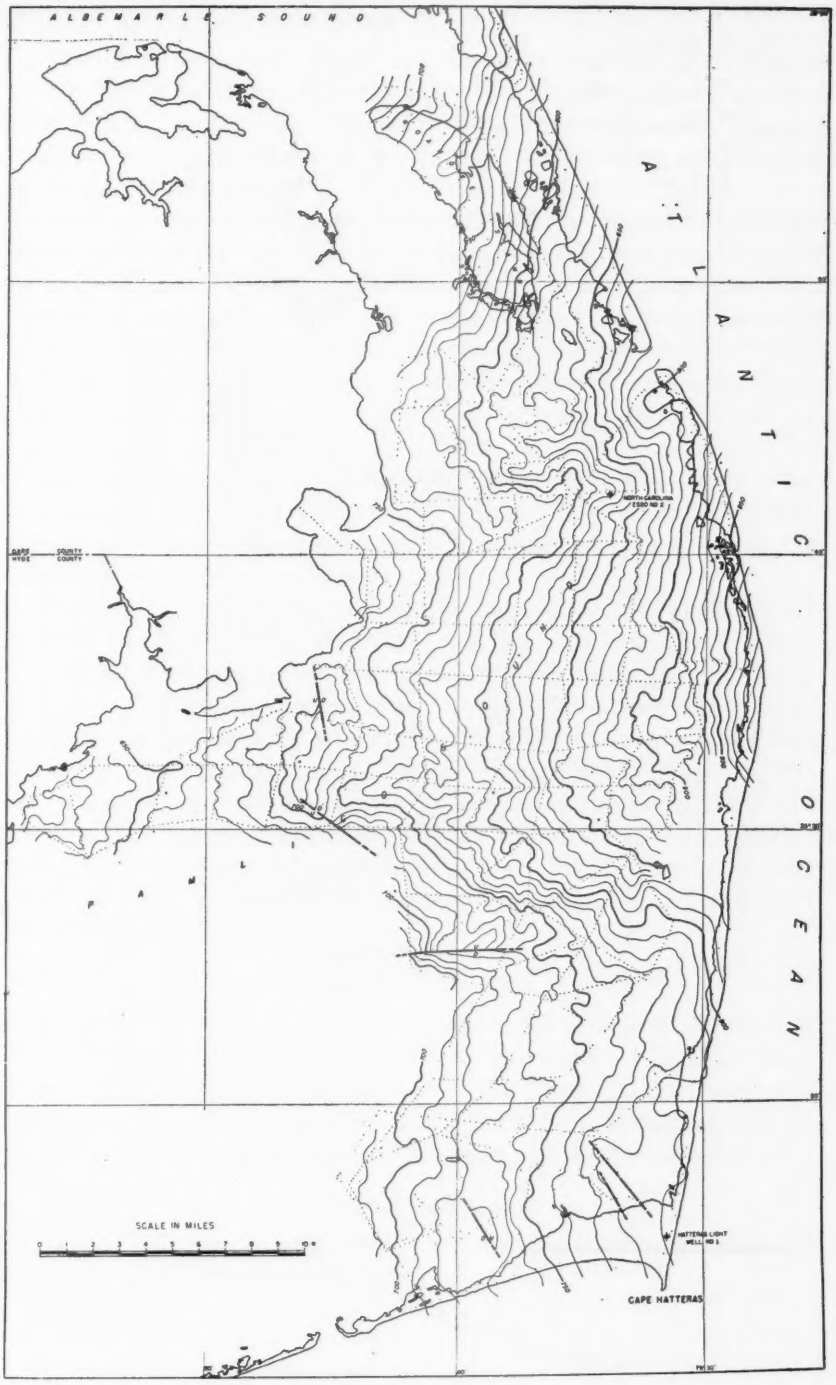

FIG. 19. Reflection survey of Pamlico Sound; reflection times to a phantom horizon near the base of the Peedee in Hatteras well.

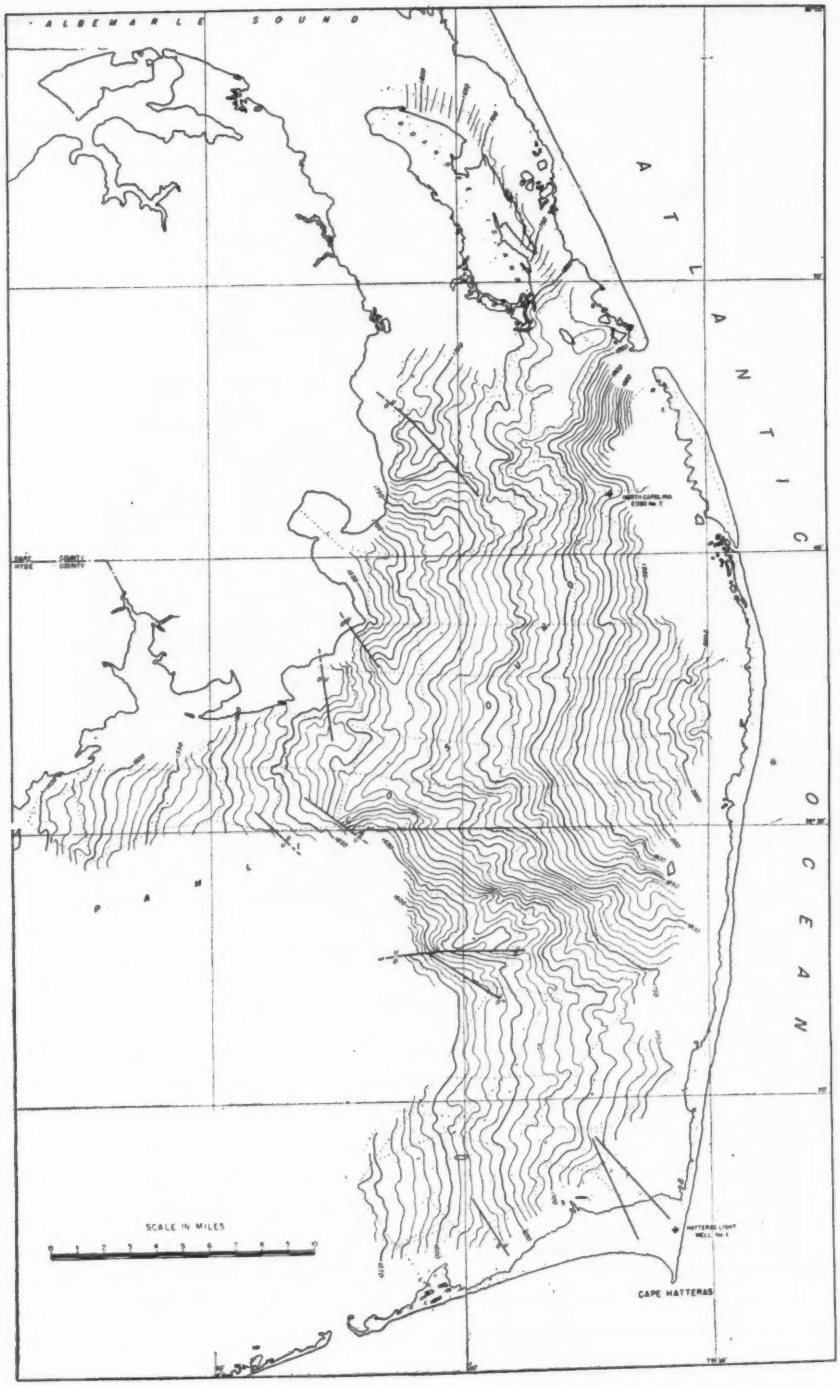

FIG. 20. Reflection survey of Pamlico Sound; reflection times to a phantom horizon in the Lower Cretaceous in the Hatteras well.

The results of the seismic survey are shown by reflection-time maps on two phantoms. Figure 19 shows reflection times to a phantom horizon which, in the Hatteras well, is near the base of the Cretaceous Peedee formation. Figure 20 is a time map for a phantom which, in the Hatteras well, is about 400 feet below the top of the Lower Cretaceous.

Since these are maps of phantom horizons, based on discontinuous reflections, and since velocity data are available at only one point, it cannot be stated with assurance that either of these maps represents the same stratigraphic horizon in all parts ofthe area. Nor have we any assurance that the velocities recorded in the Hatteras well will apply in all parts of the area. In fact, we have definite evidence for the upper phantom that it either trangresses stratigraphic horizons or that there is a velocity change between the Hatteras well and North Caroline Esso No. 2, about 30 miles to the north. From the reflection time and the Hatteras velocities we would expect the base of the Peedee in Esso No. 2 to be about 120 feet lower than in the Hatteras well; actually, it was 910 feet higher. This simply illustrates that long-distance seismic correlation with phantom horizons, or without velocity control, is dangerous.

It is believed, however, that the maps are sufficiently reliable for the local structural features. No closed structures were mapped in the area. There are a number of noses plunging to the east and northeast; the largest of these, at Latitude 35°23′, is bounded on the north by a zone of steep dip. A number of faults are shown, but they are all somewhat hypothetical, being based mostly on disappearance of reflections and misclosures in going around loops.

For the second test in the area, the prominent nose about four miles south of Oregon Inlet was selected. This well, North Caroline Esso No. 2, was drilled to a depth of 6,410 feet, and was abandoned as a dry hole. With the completion of this well, the Esso Standard Oil Company terminated its exploration activity on the Atlantic Coastal Plain.

ACKNOWLEDGMENTS

The writer is indebted to the Esso Standard Oil Company and to its parent company, Standard Oil Company (N. J.), for permission to publish these data. He is also indebted to the geophysical staff of The Carter Oil Company, who made most of the interpretations, and particularly to Dr. R. J. Watson and Mr. Dwight E. Ward, from whose excellent reports this paper was largely compiled.

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PROPAGATION OF EXPLOSIVE SOUND IN A LIQUID LAYER OVERLYING A SEMI-INFINITE ELASTIC SOLID*

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ABSTRACT

The Pekeris theory of normal mode propagation of explosion sound in two liquid layers is extended to include the case of a solid bottom. Curves giving phase velocity, group velocity, amplitude, vertical pressure distribution as a function of frequency are presented. The relative merits of geophones and hydrophones for underwater seismology and the best depth for each type of instrument are discussed in the light of the theory. The characteristics of an incoming signal are described.

INTRODUCTION

The normal mode theory of sound propagation in two and three liquid layers was given by Pekeris (1948) who solved the problem for waves originating at an impulsive point source located in the first layer. Pekeris showed conclusively that his solution fully explained most of the characteristics of explosive sounds in shallow water observed by Worzel and Ewing (1948).

The plane wave solution for sound propagation in three liquid layers in which the speed of sound in the intermediate layer is less than that in the topmost layer was investigated by Press and Ewing (1948a).

The treatment of the ocean bottom as a liquid was adequate for the shallow water data to which Pekeris applied it since the penetration into the bottom is approximately equal to the depth of water which usually involves only unconsolidated sediments. When one deals with sound propagation in the deep ocean or in shallow water underlain by rock bottom, it becomes necessary to consider the bottom as an elastic solid. Several of our recent papers have dealt with certain aspects of propagation in a liquid layer overlying an elastic solid, and in the present paper the Pekeris theory is extended to include the case of normal mode sound propagation from an impulsive point source in a liquid layer overlying a semi-infinite elastic solid. Certain derivations covered in the liquid bottom theory will not be repeated here, but reference will be made to the paper of Pekeris.

Early work by Stoneley (1926) and Sezawa (1934) dealt with the effect of the ocean on the transmission of seismic waves across a solid ocean bottom. Stoneley considered plane waves and calculated several values of phase and group velocity for long periods. Sezawa obtained an approximate solution for the propagation of cylindrical waves having great length compared to the depth of water. Lee (1934) calculated the amplitudes of Rayleigh waves for plane waves transmitted

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through an elastic solid covered by a superficial surface layer, assuming several values for the elastic constants of the two media.

Scholte (1943) gave a theory for the combined effects of gravity and compressibility in a layer of water in contact with an elastic solid bottom. Scholte's emphasis was on energy transfer from the atmosphere to the ocean bottom and he did not deal with group velocity or pay particular attention to transmission in a horizontal direction. Press and Ewing (1948b) presented curves of phase and group velocity for the first and second modes of motion of plane waves in a liquid layer superposed on a solid bottom and later (Press, *et al.*) extended the theoretical work of Lamb (1904) and Pekeris (1948) to include the case of an impulsive point source of compressional waves located within the solid bottom.

THEORY

Steady State Solution

Consider the propagation of elastic waves through the system consisting of a liquid layer of thickness H, density ρ_1 and compressional wave velocity v_1, superposed upon an infinitely thick, solid bottom of density ρ_2, compressional wave velocity α_2 and distortional wave velocity β_2. The incompressibility of the liquid is λ_1, and λ_2, μ_2 are Lame's constants for the bottom, and are related to the elastic wave velocities as follows:

$$\left.\begin{aligned} v_1^2 &= \lambda_1/\rho_1 \\ \alpha_2^2 &= (\lambda_2 + 2\mu_2)/\rho_2 \\ \beta_2^2 &= \mu_2/\rho_2 \end{aligned}\right\}. \tag{1}$$

The cartesian coordinate system is chosen with the x and y axes in the liquid surface and the z axis vertically downward. We will use the coordinates z and $r=\sqrt{x^2+y^2}$ and denote the corresponding displacements by q and w respectively. The subscripts 1 and 2 refer to the liquid layer and solid bottom respectively.

Simple Harmonic Point Source within Liquid Layer

We wish to determine the velocity potential ϕ_1 from which the component displacements q_1 and w_1 and the pressure p_1 due to a point source of compressional waves at $r=0$, $z=d$ can be obtained. In particular we will seek the normal mode solutions which predominate at large distances from the source.

We follow the procedure of Lamb (1904) in assuming simple harmonic motion $e^{i\omega t}$ and introducing the functions $\phi(r,z)$ and $\psi\ (r, z)$ defined by the equations:

$$\left.\begin{aligned} q_1 &= \partial\phi_1/\partial r \\ w_1 &= \partial\phi_1/\partial z \\ q_2 &= \partial\phi_2/\partial r + \partial^2\psi_2/\partial r\partial z \\ w_2 &= \partial\phi_2/\partial z + \partial^2\psi_2/\partial z^2 + \omega^2/\beta_2^2\psi_2 \end{aligned}\right\}. \tag{2}$$

The vertical stress p_{zz} and the tangential stress p_{zr} can be expressed in terms of q, w, ϕ, ψ and the elastic constants as follows:

$$p_{zz} = \lambda\nabla^2\phi + 2\mu\partial w/\partial z \tag{3}$$

$$p_{zr} = \mu(\partial q/\partial z + \partial w/\partial r). \tag{4}$$

It is required that the functions ϕ and ψ satisfy the wave equations (reduced for simple harmonic motion):

$$(\nabla^2 + \omega^2/v_1^2)\phi_1 = 0 \tag{5}$$

$$(\nabla^2 + \omega^2/\alpha_2^2)\phi_2 = 0 \tag{6}$$

$$(\nabla^2 + \omega^2/\beta_2^2)\psi_2 = 0 \tag{7}$$

where

$$\nabla^2 = \partial^2/\partial r^2 + \frac{1}{r}\partial/\partial r + \partial^2/\partial z^2$$

Solutions of (5), (6), and (7) must satisfy the boundary conditions:

$$(p_{zz})_1 = 0 \quad \text{at} \quad z = 0 \tag{8}$$

$$(p_{zz})_1' = (p_{zz})_2 \quad \text{at} \quad z = H \tag{9}$$

$$(p_{zr})_2 = 0 \quad \text{at} \quad z = H \tag{10}$$

$$w_1' = w_2 \quad \text{at} \quad z = H. \tag{11}$$

The meaning of the primed symbols is given in the next paragraph.

Our procedure will be to first obtain the solutions to the problem where a periodic pressure is applied to the entire plane $z=d$ symmetrically about the z axis and then to pass to the case of a point source utilizing the Fourier-Bessel integral. We shall represent a point source located at $r=0$, $z=d$ by requiring continuity of pressure in the plane $z=d$ and continuity of vertical displacement w everywhere in the same plane except at the point source where the fluid above and below the source moves in opposite directions, the discontinuity in w here becoming proportional to a function $F(r)$ which vanishes everywhere except at $r=0$ where it becomes infinite in such a manner that its integral over the plane $z=d$ is finite. It is convenient to divide the liquid layer into regions above and below this plane indicated by primed and unprimed symbols respectively.

Typical solutions of (5), (6), and (7) are of the form:

$$\phi_1 = A \sin(\xi z) J_0(kr) \tag{12}$$

$$\phi_1' = [B \sin(\xi z) + C \cos(\xi z)] J_0(kr) \tag{13}$$

$$\phi_2 = De^{-\eta z} J_0(kr) \tag{14}$$

$$\psi_2 = Ee^{-\zeta z} J_0(kr) \tag{15}$$

where the separation constants ξ, η, ζ, obtained by substituting (12)–(15) in (5)–(7) are

$$\xi^2 = \omega^2/v_1^2 - k^2, \qquad \eta^2 = k^2 - \omega^2/\alpha_2^2, \qquad \zeta^2 = k^2 - \omega^2/\beta_2^2 \tag{16}$$

ξ, η, ζ are positive real or negative imaginary following the convention adopted by Pekeris. (1948).

These solutions must satisfy two additional boundary conditions at the plane $z=d$. We require continuity of pressure

$$(p_{zz})_1 = (p_{zz})_1' \quad \text{at} \quad z = d \tag{17}$$

and a discontinuity in vertical displacement given by

$$(\partial\phi_1/\partial z) - (\partial\phi_1/\partial z)' = 2ZJ_0(kr) \tag{18}$$

the fluid above and below the plane moving in opposite directions.

The expression for ϕ_1' is the general form. ϕ_1 has been chosen to satisfy the first boundary condition (8). The functions ϕ_2 and ψ_2 are taken to decrease exponentially with depth since we are interested in solutions for which the loss of energy by refraction into the bottom is zero.

The constants A, B, C, D, E determined by substituting equations (12)–(15) in the boundary condition equations (9)–(11) and (17)–(18) are as follows:

$$A = \frac{2Z}{\xi} \frac{\left\{\frac{\rho_1}{\rho_2}\frac{\omega^4}{\beta_2^4}\frac{\eta}{\xi}\sin\xi(H-d) - [4k^2\eta\zeta - (2k^2-\omega^2/\beta_2^2)^2]\cos\xi(H-d)\right\}}{\left\{\frac{\rho_1}{\rho_2}\frac{\omega^4}{\beta_2^4}\frac{\eta}{\xi}\sin(\xi H) - [4k^2\eta\zeta - (2k^2-\omega^2/\beta_2^2)^2]\cos(\xi H)\right\}} \tag{19}$$

$$B = -\frac{2Z}{\xi}\sin(\xi d)\frac{\left\{\frac{\rho_1}{\rho_2}\frac{\omega^4}{\beta_2^4}\frac{\eta}{\xi}\cos(\xi H) + [4k^2\eta\zeta - (2k^2-\omega^2/\beta_2^2)^2]\sin(\xi H)\right\}}{\left\{\frac{\rho_1}{\rho_2}\frac{\omega^2}{\beta_2^4}\frac{\eta}{\xi}\sin(\xi H) - [4k^2\eta\zeta - (2k^2-\omega^2/\beta_2^2)^2]\cos(\xi H)\right\}} \tag{20}$$

$$C = \frac{2Z}{\xi}\sin(\xi d) \tag{21}$$

$$D = -\frac{2Z}{\xi}\sin(\xi d)\frac{\frac{\rho_1}{\rho_2}\frac{\omega^2}{\beta_2^2}(2k^2-\omega^2/\beta_2^2)e^{\eta H}}{\left\{\frac{\rho_1}{\rho_2}\frac{\omega^4}{\beta_2^4}\frac{\eta}{\xi}\sin(\xi H) - [4k^2\eta\zeta - (2k^2-\omega^2/\beta_2^2)^2]\cos(\xi H)\right\}} \tag{22}$$

$$E = -\frac{2Z}{\xi}\sin(\xi d)\frac{2\frac{\rho_1}{\rho_2}\frac{\omega^2}{\beta_2^2}\eta e^{\xi H}}{\left\{\frac{\rho_1}{\rho_2}\frac{\omega^4}{\beta_2^4}\frac{\eta}{\xi}\sin(\xi H) - [4k^2\eta\zeta - (2k^2-\omega^2/\beta_2^2)^2]\cos(\xi H)\right\}} \tag{23}$$

We now generalize the discontinuity in w by means of the Fourier-Bessel integral:

$$F(r) = \int_0^\infty J_0(kr)\,kdk \int_0^\infty F(\lambda)J_0(k\lambda)\lambda d\lambda \tag{24}$$

and we choose $F(\lambda)$ to vanish for all but infinitesimal values of λ in such a manner that its integral over the plane $z=d$ is unity, or

$$\int_0^\infty F(\lambda)2\pi\lambda d\lambda = \text{finite.} \tag{25}$$

Thus if we take $Z=kdk$ in the solutions (12)–(15) and (19)–(23) and integrate with respect to k from 0 to ∞ we obtain solutions which satisfy the conditions at the boundaries and meet the additional requirements of a point source, namely, continuity of pressure in the plane $z=d$ and continuity of vertical displacement everywhere in this plane except at $r=0$ where the discontinuity becomes proportional to $F(r)=\int J_0^\infty(kr)kdk$ which becomes infinite in such a way that its integral over the plane $z=d$ is finite.

The formal solutions for a periodic point source are therefore:

$$\phi_1 = 2e^{i\omega t}\int_0^\infty J_0(kr)\,kdk\,\frac{\sin(\xi z)}{\xi} \cdot \left\{ \frac{\dfrac{\rho_1}{\rho_2}\dfrac{\omega^4}{\beta_2{}^4}\dfrac{\eta}{\xi}\sin\xi(H-d) - \left[4k^2\eta\zeta - \left(2k^2 - \dfrac{\omega^2}{\beta_2{}^2}\right)^2\right]\cos\xi(H-d)}{\dfrac{\rho_1}{\rho_2}\dfrac{\omega^4}{\beta_2{}^4}\dfrac{\eta}{\xi}\sin(\xi H) - \left[4k^2\eta\zeta - \left(2k^2 - \dfrac{\omega^2}{\beta_2{}^2}\right)^2\right]\cos(\xi H)} \right\} \tag{26}$$

$$0 \leqq z \leqq d$$

$$\phi_1' = 2e^{i\omega t}\int_0^\infty J_0(kr)\,kdk\,\frac{\sin(\xi d)}{\xi} \cdot \left\{ \frac{\dfrac{\rho_1}{\rho_2}\dfrac{\omega^4}{\beta_2{}^4}\dfrac{\eta}{\xi}\sin\xi(H-z) - \left[4k^2\eta\zeta - \left(2k^2 - \dfrac{\omega^2}{\beta_2{}^2}\right)^2\right]\cos\xi(H-z)}{\dfrac{\rho_1}{\rho_2}\dfrac{\omega^4}{\beta_2{}^4}\dfrac{\eta}{\xi}\sin(\xi H) - \left[4k^2\eta\zeta - \left(2k^2 - \dfrac{\omega_2{}^2}{\beta_2{}^2}\right)^2\right]\cos(\xi H)} \right\} \tag{27}$$

$$d \leqq z \leqq H$$

$$\phi_2 = -2e^{i\omega t}\int_0^\infty J_0(kr)\,kdk\,\frac{\sin(\xi d)}{\xi} \cdot \left\{ \frac{\dfrac{\rho_1}{\rho_2}\dfrac{\omega^2}{\beta_2{}^2}\left(2k^2 - \dfrac{\omega^2}{\beta_2{}^2}\right)e^{-\eta(z-H)}}{\dfrac{\rho_1}{\rho_2}\dfrac{\omega^4}{\beta_2{}^4}\dfrac{\eta}{\xi}\sin(\xi H) - \left[4k^2\eta\zeta - \left(2k^2 - \dfrac{\omega^2}{\beta_2{}^2}\right)^2\right]\cos(\xi H)} \right\} \tag{28}$$

$$z \geqq H$$

$$\psi_2 = -2e^{i\omega t}\int_0^\infty J_0(kr)\,kdk\,\frac{\sin(\xi d)}{\xi}\cdot\left\{\frac{\dfrac{\rho_1}{\rho_2}\dfrac{\omega^2}{\beta_2{}^2}\eta e^{-\zeta(z-H)}}{\dfrac{\rho_1}{\rho_2}\dfrac{\omega^4}{\beta_2{}^4}\dfrac{\eta}{\xi}\sin(\xi H)-\left[4k^2\eta\zeta-\left(2k^2-\dfrac{\omega^2}{\beta_2{}^2}\right)^2\right]\cos(\xi H)}\right\} \tag{29}$$

$$z \geqq H.$$

Integrals of this general type have been evaluated by Lamb, (1904), Nakano (1925), Sezawa (1935), and Pekeris (1948). The procedure is to transform the path of integration to the complex k-plane. The solutions can then be expressed as the sum of the residues of the integrands and two integrals along branch lines corresponding to the branch points $k=\omega/\alpha_2$ and $k=\omega/\beta_2$. The residues which diminish as $r^{-1/2}$ give the normal mode solutions, whereas the branch line integrals diminish as r^{-2}, and become negligible for large r.

Following this procedure and neglecting for the while the contributions of the branch line integrals, we find for large values of r:

$$\phi_1 = \frac{2\pi}{H}\sqrt{\frac{2}{\pi r}}\sum_n \frac{1}{\sqrt{k_n}}\frac{\sin(\xi_n z)}{\xi_n}e^{i(\omega t-k_n r-\omega/4)}$$

$$\frac{k_n H\left\{\dfrac{\rho_1}{\rho_2}\dfrac{\omega^4}{\beta_2{}^4}\dfrac{\eta_n}{\xi_n}\sin\xi_n(H-d)-\left[4k_n{}^2\eta_n\zeta_n-\left(2k_n{}^2-\dfrac{\omega^2}{\beta_2{}^2}\right)^2\right]\cos\xi_n(H-d)\right\}}{\dfrac{\partial}{\partial k}\left\{\dfrac{\rho_1}{\rho_2}\dfrac{\omega^4}{\beta_2{}^4}\dfrac{\eta_n}{\xi_n}\sin(\xi_n H)-\left[4k_n{}^2\eta_n\zeta_n-\left(2k_n{}^2-\dfrac{\omega^2}{\beta_2{}^2}\right)^2\right]\cos(\xi_n H)\right\}} \tag{30}$$

$$0 \leqq z \leqq d.$$

Corresponding expressions for ϕ_1', ϕ_2 and ψ_2 are readily obtainable. The subscript n indicates that the quantity is to be evaluated at $k=k_n$, where k_n are the roots of the period equation obtained by setting the denominators of (26)–(29) equal to zero, namely,

$$\frac{\rho_1}{\rho_2}\frac{\omega^4}{\beta_2{}^4}\frac{\eta}{\xi}\tan(\xi H)-\left[4k^2\eta\zeta-\left(2k^2-\frac{\omega^2}{\beta_2{}^2}\right)^2\right]=0 \tag{31}$$

From the exponential factor in (30) it can be seen that the phase velocity c_n can be expressed by

$$c_n = \omega/k_n \tag{32}$$

and the normal mode solutions can be written in their final form:

$$\phi_1 = \phi_1' = \frac{2\pi}{H}\sqrt{\frac{2}{\pi r}}\sum_n \frac{1}{\sqrt{k_n}} e^{i(\omega t - k_n r - \pi/4)}\Phi_1(k_n)\sin(\xi_n d)\sin(\xi_n z) \qquad (33)$$

$$0 \leqq z \leqq H$$

$$\phi_2 = \frac{2\pi}{H}\sqrt{\frac{2}{\pi r}}\sum_n \frac{1}{\sqrt{k_n}} e^{i(\omega t - k_n r - \pi/4)}\Phi_2(k_n)\sin(\xi_n d)e^{-\eta(z-H)} \qquad (34)$$

$$z \geqq H$$

$$\psi_2 = 2\pi\sqrt{\frac{2}{\pi r}}\sum_n \frac{1}{\sqrt{k_n}} e^{i(\omega t - k_n r - \pi/4)}\Psi_2(k_n)\sin(\xi_n d)e^{-\zeta(z-H)} \qquad (35)$$

$$z \geqq H$$

where

$$\Phi_1 = -\frac{\dfrac{\rho_1}{\rho_2}\dfrac{c^4}{\beta_2^4}\dfrac{\eta_n}{\xi_n}k_n H}{\sqrt{c^2/v_1^2 - 1}\,\{\ \}\cos(\xi_n H)} \qquad (36)$$

$$\Phi_2 = -\frac{\dfrac{\rho_1}{\rho_2}\dfrac{c^2}{\beta_2^2}(2 - c^2/\beta_2^2)k_n H}{\sqrt{c^2/v_1^2 - 1}\,\{\ \}} \qquad (37)$$

$$\Psi_2 = -\frac{\dfrac{\rho_1}{\rho_2}\dfrac{c^2}{\beta_2^2}\dfrac{\eta_n}{\xi_n}}{\{\ \}} \qquad (38)$$

$$\begin{aligned}\{\ \} = \frac{\rho_1}{\rho_2}\frac{c^4}{\beta_2^4}\Bigg\{&\frac{\sin(\xi_n H)}{\sqrt{c^2/v_1^2 - 1}\ \sqrt{1 - c^2/\alpha_2^2}}\left[1 + \frac{1 - c^2/\alpha_2^2}{c^2/v_1^2 - 1}\right] \\ &- \left[\frac{k_n H\sqrt{1 - c^2/\alpha_2^2}}{(c^2/v_1^2 - 1)}\sec(\xi_n H)\right]\Bigg\} - 4\Bigg\{\frac{\sqrt{1 - c^2/\beta_2^2}}{\sqrt{1 - c^2/\alpha_2^2}} \\ &+ \frac{\sqrt{1 - c^2/\alpha_2^2}}{\sqrt{1 - c^2/\beta_2^2}} \\ &+ 2\sqrt{1 - c^2/\alpha_2^2}\sqrt{1 - c^2/\beta_2^2} - 2(2 - c^2/\beta_2^2)\Bigg\}\cos(\xi_n H)\end{aligned} \qquad (39)$$

and

$$\left.\begin{aligned}\xi_n &= k_n\sqrt{c^2/v_1^2 - 1} \\ \eta_n &= k_n\sqrt{1 - c^2/\alpha_2^2} \\ \zeta_n &= k_n\sqrt{1 - c^2/\beta_2^2}\end{aligned}\right\}. \qquad (40)$$

Equation (29) can be rewritten in the dimensionless form:

$$\tan\left(k_n H\sqrt{c^2/v_1^2 - 1}\right) = \frac{\rho_2}{\rho_1}\frac{\beta_2^4}{c^4}\frac{\sqrt{c^2/v_1^2 - 1}}{\sqrt{1 - c^2/\alpha_2^2}}\left[4\sqrt{1 - c^2/\alpha_2^2}\sqrt{1 - c^2/\beta_2^2} - (2 - c^2/\beta_2^2)^2\right]. \quad (41)$$

The discussion of the previous equation given in earlier papers will be repeated here.

This equation defines an implicit relationship between the frequency $f = ck_n/2\pi$ and the phase velocity c, with the elastic constants of the acoustic system as parameters. It is evident that the wave system defined by (33)–(35) will be attenuated for k_n complex, the degree of attenuation depending on the magnitude of the imaginary component. The energy loss associated with damped propagation is due to the refraction of waves from the liquid layer into the solid bottom. For the case $\alpha_2 > \beta_2 > v_1$ which is considered in this paper, undamped propagation will occur for the cases:

$$I \qquad \alpha_2 > \beta_2 \geqq c \geqq v_1$$

$$II \qquad \alpha_2 > \beta_2 > v_1 \geqq c.$$

Only case I is considered here.

From the form of the period equation (41), it can be seen that $k_n H$ (and hence frequency) is a multiple valued function of phase velocity, each value belonging to a distinct mode of propagation. The summations indicated in (31)–(33) are to be carried out over all the modes $n = 1$ to $n = \infty$. The amplitude factors $\Phi_1/\sqrt{k_n}$ and $\Phi_2/\sqrt{k_n}$, $\Psi_2/\sqrt{k_n}$ give the strength of excitation in the first and second layer for each mode as a function of the frequency. A plot of Φ_1 for the first and second modes appears in Figure 7 as a function of a dimensionless parameter proportional to frequency.

The factor $\sin(\xi_n d)$ shows the influence of the depth of the source on the amplitudes of the different modes. The vertical pressure distribution for each mode is given by the factor $\sin(\xi_n z)$ which is plotted in Figure 8 for the first two modes.

It can be shown (Press & Ewing, 1948b) that the period equation (41) expresses the condition of constructive interference between plane waves undergoing multiple reflection in the liquid layer at angles of incidence beyond the critical angle of reflection θ_c, where $\sin\theta_c = v_1/\beta_2$. With this simplified point of view each mode represents a different order of interference and the disturbance at a distant point is obtained by the superposition of waves arriving at the point along the oblique ray paths (defined by the angle of incidence θ) for which constructive interference occurs. For the case of plane waves the wave number k in the previous discussion can be expressed by $k = (2\pi/l)\sin\theta$ where l is the wavelength measured along an oblique ray path.

Generalization for an Arbitrary Pulse

In a dispersive medium in which an arbitrary initial disturbance occurs, the energy associated with each period is known to propagate with the group velocity given by the formula

$$U = c + (kH)\,(dc)/d(kH)\,. \tag{42}$$

The period equation (41) was used to calculate numerically the phase velocity as a function of kH. The group velocity was subsequently determined from equation (42), using the values of $dc/d(kH)$ obtained by numerical differentiation. The results of these computations for $\beta_2 \geqq c \geqq v_1$ (case I above) are shown in Figures 1, 2, and 3, where c/v_1 and U/v_1 are plotted as functions of the dimensionless parameter $\gamma = H/l = kHc/2\pi v_1 = Hf/v_1$ for three cases a) $\rho_2/\rho_1 = 2.5$, $\alpha_2 = \sqrt{3}\beta_2$, $\beta_2 = 3v_1$, b) $\rho_2/\rho_1 = 2.5$, $\alpha_2 = \sqrt{3}\,\beta_2$, $\beta_2 = 2v_1$, and c) $\rho_2/\rho_1 = 2.0$, $\alpha_2 = \sqrt{3}\,\beta_2$, $\beta_2 = 1.5v_1$, which represent in an approximate way the conditions for basaltic, granitic and sedimentary bottoms for which $\lambda = \mu$ or Poissons constant $\sigma = 0.25$. For each case the first two modes are plotted.

A study of these curves reveals that the phase and group velocity of the first mode ($n = 1$) approach the velocity of Rayleigh waves ($c_R = 0.9194\ \beta_2$) in the bottom layer as $\gamma \to 0$ or as the wavelength becomes very long in comparison to the thickness of the first layer. As c/v_1 and $U/v_1 \to 1$, γ approaches a limiting value.

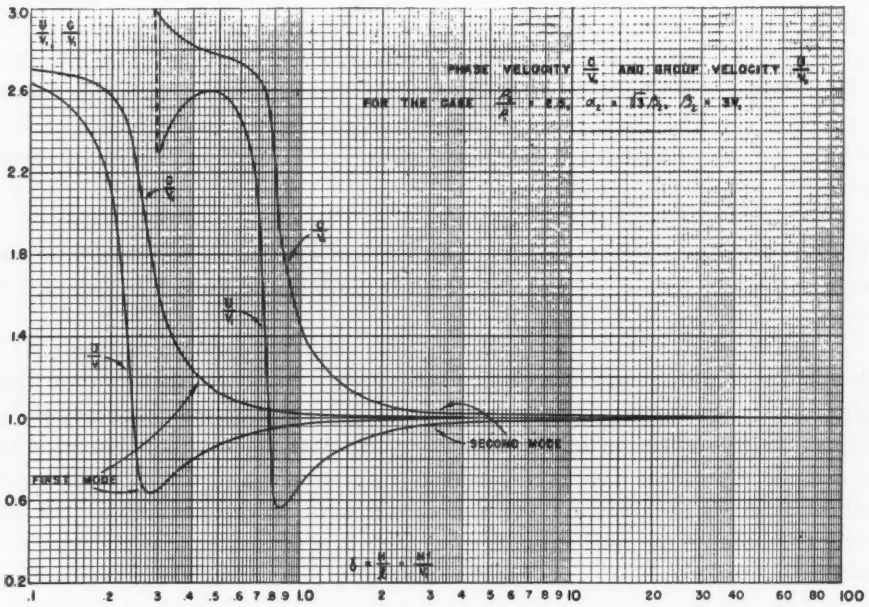

FIG. 1. Phase and group velocity curves in the first and second modes for case a.

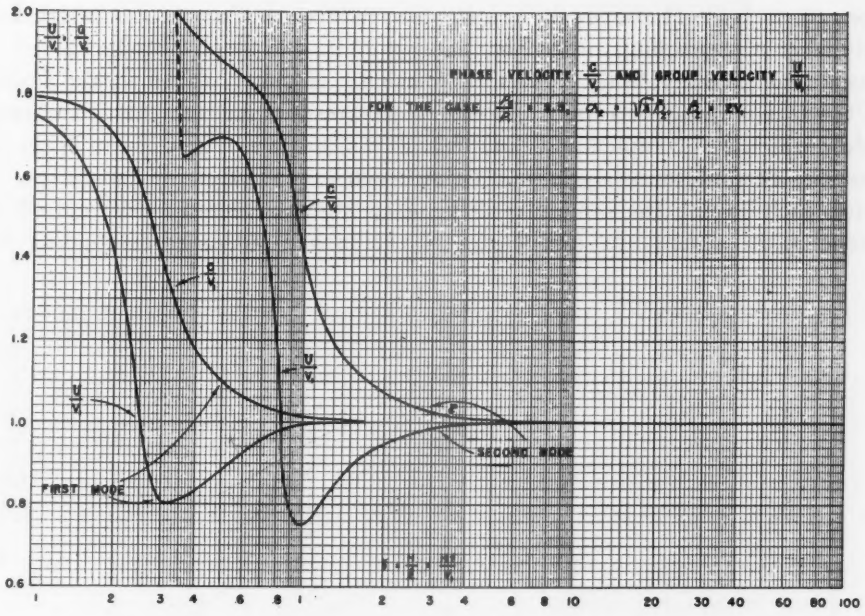

FIG. 2. Phase and group velocity curves in the first and second modes for case b.

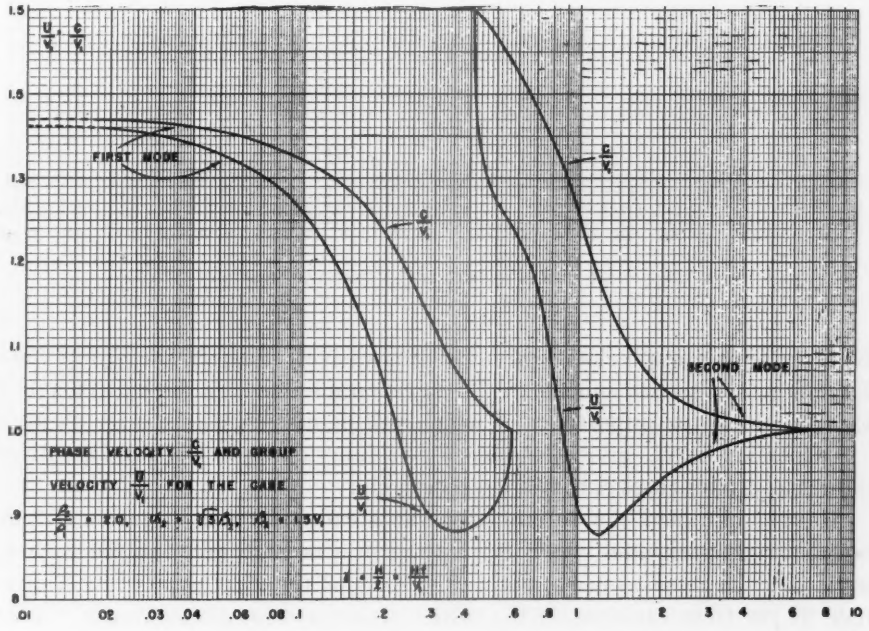

FIG. 3. Phase and group velocity curves in the first and second modes for case c.

For $c/v_1 < 1$ (case II above) the propagation reduces to that of a boundary wave (Stoneley wave) along the bottom interface. In the second mode ($n=2$) the phase and group velocity equals the velocity of shear waves in the bottom ($c/v_1 = U/v_1 = \beta_2/v_1$) for a limiting value of γ corresponding to a cut-off frequency below which k is complex and damping occurs. For c and U close to v_1 the frequencies become infinitely large. Higher modes of propagation ($n=3, 4, \ldots$) exist, each having the same cut-off velocity but increasingly large cut-off frequencies. In general the frequencies of the higher modes corresponding to a

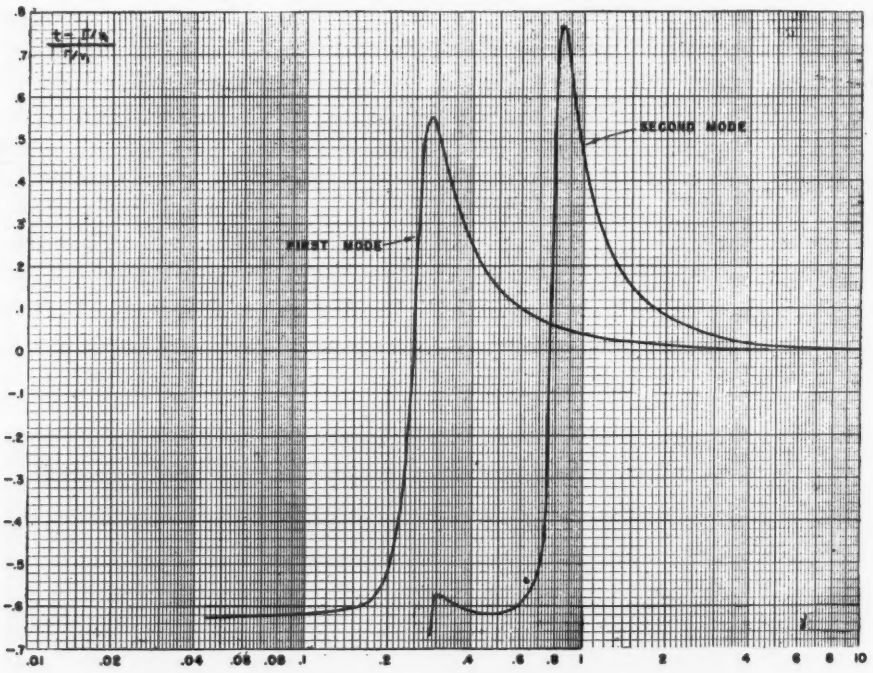

FIG. 4. Dispersion curves relating travel time and frequency for case a.

given phase or group velocity become progressively higher. The group velocity of the first and second modes are further characterized by the existence of stationary values, the importance of which will be discussed in a later paragraph.

Dispersion curves giving frequency as a function of arrival time are given in Figures 4, 5, 6 for cases a, b, and c respectively.

Having obtained the solution for the steady state propagation of simple harmonic compressional waves originating in a point source located within the liquid layer, it remains yet to obtain the solution for an arbitrary initial disturbance. If the time variation of the initial disturbance at the source is $f(t)$ represented by its Fourier transform

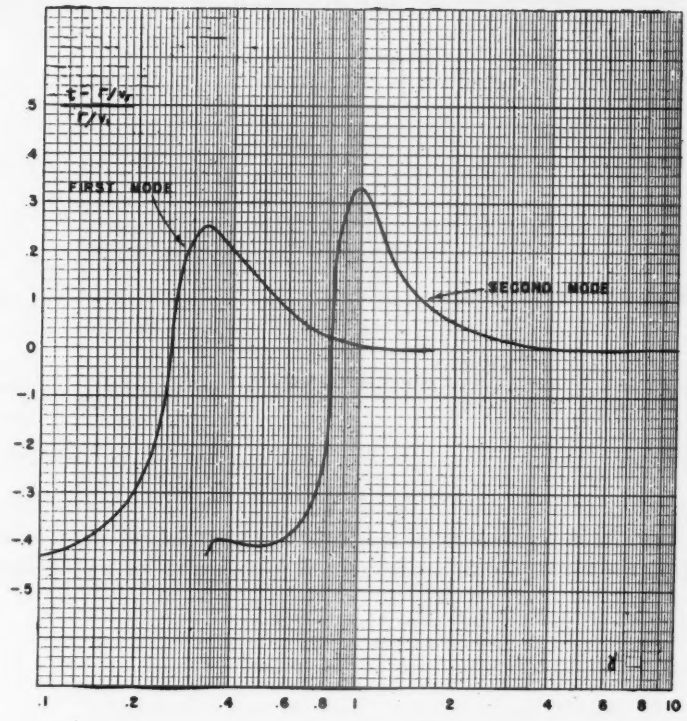

FIG. 5. Dispersion curves relating travel time and frequency for case b.

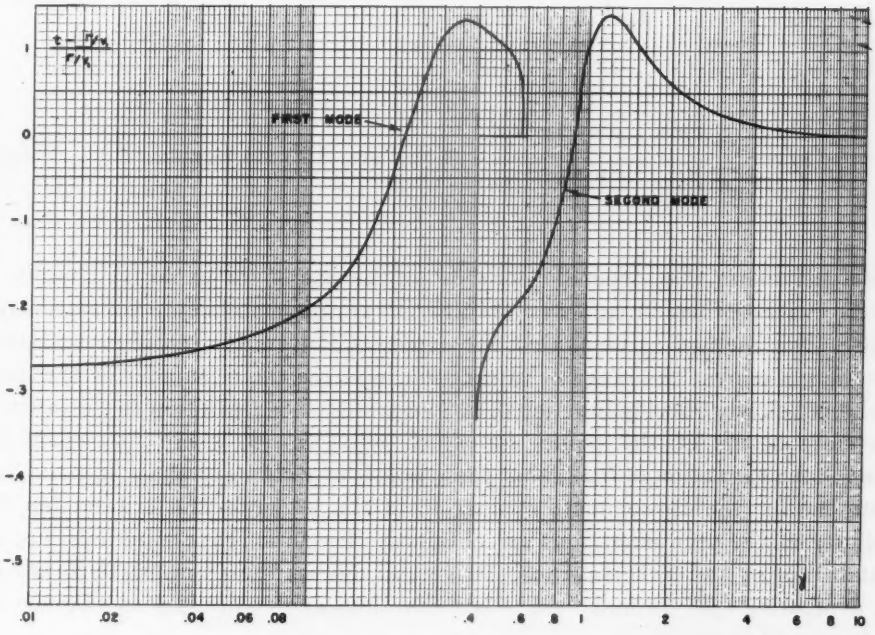

FIG. 6. Dispersion curves relating travel time and frequency for case c.

$$g(w) = \int_{-\infty}^{\infty} e^{-i\omega t} f(t)dt \tag{43}$$

then

$$f(t) = \frac{1}{2\pi}\int_{-\infty}^{\infty} e^{i\omega t} g(w)dw \tag{44}$$

the potential ϕ_1 can be written:

$$\phi_1 = \frac{1}{H}\sqrt{\frac{2}{\pi r}}\sum_n \int_{-\infty}^{\infty} \frac{g(\omega)}{\sqrt{k_n}} e^{i(\omega t - k_n r - \pi/4)}\Phi_1(k_n)\sin(\xi_n d)\sin(\xi_n z)d\omega \tag{45}$$

$$0 \leqq z \leqq H$$

The corresponding expressions for ϕ_2 and ψ_2 can be readily obtained in the same manner. In (45) k_n is a function of ω through (32) and (41). We follow Pekeris in representing the initial disturbance created in an explosion as follows:

$$\left.\begin{aligned} f(t) &= e^{-\sigma t} \qquad t > 0 \\ &= 0 \qquad t < 0 \end{aligned}\right\} \tag{46}$$

where

$$f(t) = \frac{1}{2\pi}\int_{-\infty}^{\infty} \frac{e^{i\omega t}}{(\sigma + i\omega)}d\omega, \qquad g(\omega) = \frac{1}{\sigma + i\omega} \tag{47}$$

and

$$\phi_1 = \frac{1}{H}\sqrt{\frac{2}{\pi r}}\sum_n \int_{-\infty}^{\infty} \frac{e^{i(\omega t - k_n r - \pi/4)}}{\sqrt{k_n}(\sigma + i\omega)}\Phi_1(k_n)\sin(\xi_n d)\sin(\xi_n z)d\omega \tag{48}$$

$$0 \leqq z \leqq H$$

σ is a parameter that depends primarily on the size of the explosive charge.

To evaluate these integrals we use Kelvin's approximate method of stationary phase. This method assumes that the exponential term is a rapidly oscillating function of ω over the range of integration, whereas the remainder of the integrand is a slowly varying function of ω. The principal contribution to the integral therefore occurs at the points for which $\delta f(\omega)/\delta\omega = 0$, where $f(\omega) = (\omega t - k_n r - \pi/4)$. An expansion of $f(\omega)$ about these points of stationary phase is made and formulae for the approximate evaluation of the integrals and criteria for the validity of the approximations are obtained. Havelock (1914), Jeffreys, (1926) Lamb (1932), and Pekeris (1948) derive and discuss the appropriate formulae. In evaluating (48) we make use of the equations and computations as given by Pekeris and obtain:

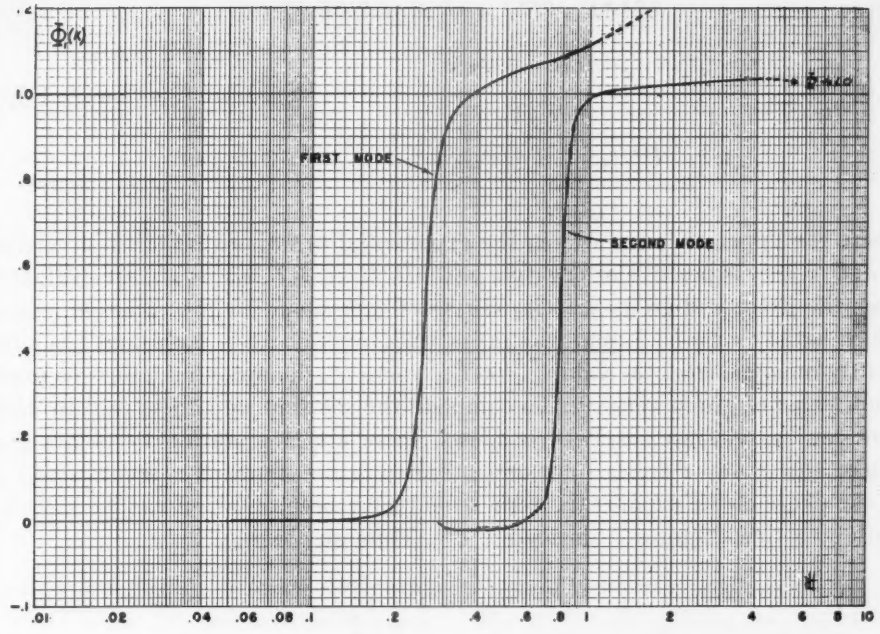

FIG. 7. Excitation function for the first and second modes of case a.

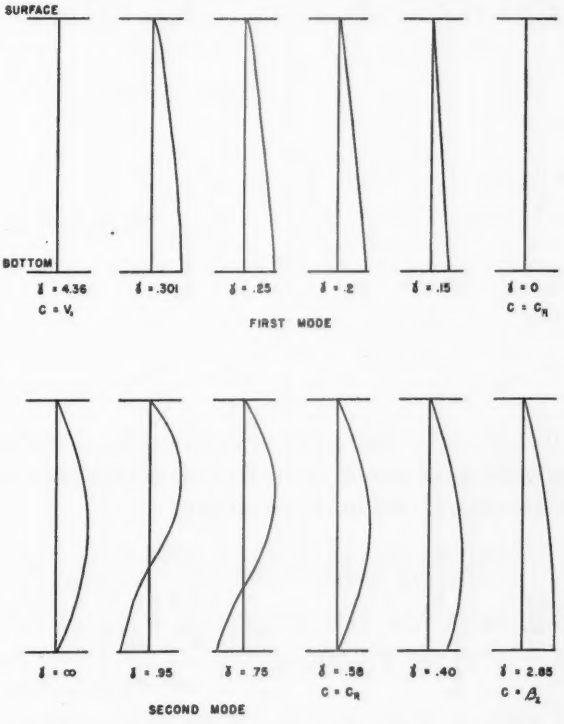

FIG. 8. Vertical pressure distribution in the first and second modes for case a.

$$\phi_1 = \frac{2V_1}{Hr} \sum_n \frac{e^{i(\omega_0 t - k_n r - \pi/4 \pm \pi/4)}}{\left[\frac{\gamma}{c/v_1} \frac{1}{U^2/v_1^2} \left|\frac{dU/V_1}{d\gamma}\right|\right]_n^{1/2} (\sigma + i\omega)} \Phi_1(k_n) \sin(\xi_n d) \sin(\xi_n z) \quad (49)$$

$$0 \leqq z \leqq H$$

where the upper or lower sign in the exponential term is to be taken according as $d(U/v_1)/d\gamma$ is positive or negative and kH, U/v_1, $d(U/v_1)/d\gamma$,ω_0, are evaluated from the phase and group velocity curves of each mode for the values of r and t which satisfy $r/t = U$. Equation (49) is valid provided r is large and t is sufficiently removed from the value $t_m = r/U_m$ where U_m denotes a minimum or maximum value of group velocity. To complete the solution we add to (49) its complex conjugate, since, as Pekeris shows, there are two stationary points $\pm\omega_0$ where $\delta f(\omega_0)/\delta\omega = 0$ and a solution similar to (49) except for a reversal in sign of the phase of the exponential term would have been obtained had we assumed initially a time factor $e^{-i\omega t}$ instead of $e^{i\omega t}$. Thus we obtain

$$\phi_1 = \frac{4V_1}{Hr} \sum_n \frac{\cos\left[\omega_0 t - k_n r - \tan^{-1}\left(\frac{\omega}{\sigma}\right)\right]}{\left[\frac{\gamma}{c/v_1} \frac{1}{U^2/v_1^2} \left|\frac{dU/v_1}{d\gamma}\right| (\sigma^2 + \omega^2)\right]_n^{1/2}} \Phi_1(k_n) \sin(\xi_n d) \sin(\xi_n z) \quad (50)$$

$$0 \leqq z \leqq H$$

for $$\frac{dU/v_1}{d\gamma} > 0 \qquad \text{and}$$

$$\phi_1 = \frac{4V_1}{Hr} \sum_n \frac{\cos\left[\omega_0 t - k_n r - \tan^{-1}\left(\frac{\omega}{\sigma}\right) - \pi/2\right]}{\left[\frac{\gamma}{c/v_1} \frac{1}{U^2/v_1^2} \left|\frac{dU/v_1}{d\gamma}\right| (\sigma^2 + \omega^2)\right]_n^{1/2}} \Phi_1(k_n) \sin(\xi_n d) \sin(\xi_n z) \quad (51)$$

$$0 \leqq z \leqq H$$

for $$\frac{dU/v_1}{d\gamma} < 0$$

For t close to $t_m = r/U_m$, where the group velocity is stationary, a further approximation involving the second derivative as the expansion of $f(\omega)$ is required in order to evaluate (45), giving for large ranges r:

$$\phi_1 = \frac{4V_1}{3^{2/3} H r^{\eta/6}} \sum_n \frac{\cos\left[\omega_0 t - k_n r - \tan^{-1}\left(\frac{\omega}{\sigma}\right) - \pi/4\right]}{\left[(\sigma^2 + \omega^2) k/2\pi\right]_n^{1/2} \left[\frac{H^2}{2\pi} \frac{d\bar{Z}}{d\gamma}\right]_n^{1/3}}$$

$$E(v) \Phi_1(k_n) \sin(\xi_n d) \sin(\xi_n z) \quad (52)$$

$$0 \leqq z \leqq H$$

where

$$E(v) = v^{1/3}[J_{-1/3}(v) + J_{1/3}(v)] \quad \begin{cases} t < r/U_{\min} \\ t > r/U_{\max} \end{cases} \tag{53}$$

$$E(v) = v^{1/3}[I_{-1/3}(v) - I_{1/3}(v)] \quad \begin{cases} t > r/U_{\min} \\ t < r/U_{\max} \end{cases}$$

$$Z = \frac{v_1^2}{H}\frac{d^2k}{d\omega^2} = -\frac{v_1}{2\pi U^2}\frac{dU}{d\gamma} \tag{54}$$

and

$$v = \frac{4\sqrt{\pi}}{\sqrt[3]{-\frac{dZ}{d\gamma}}}\left(\frac{r}{H}\right)\left(\frac{v_1}{U} - \frac{v_1}{U_m}\right)^{3/2} \tag{55}$$

Pekeris has given the name Airy phase to waves associated with a maximum value. The factor $E(v)$ represents the envelope of the Airy phase and is plotted

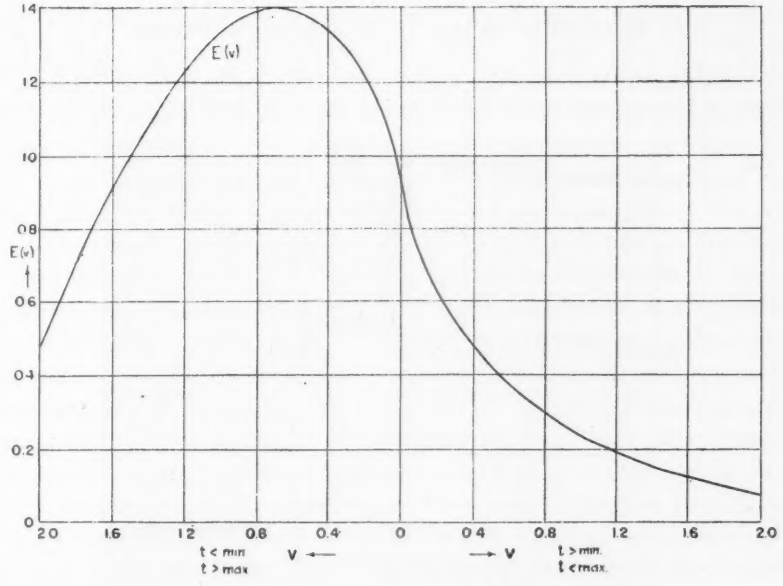

FIG. 9. Envelope of the Airy phase (after Pekeris).

in Figure 9 from the data given by Pekeris. It is to be noted that the Airy phase amplitude falls off only as $r^{-5/6}$, in contrast to the r^{-1} decay of waves travelling at other values of group velocity.

The relative amplitudes of the velocity potential γ_1 when both the charge and hydrophone are on bottom can be discussed with the aid of Figure 10 where the amplitude factor

$$G = \frac{\Phi_1(k_n)\sin^2(\xi_n H)}{\left[\frac{\gamma}{c/v_1}\,\frac{1}{U^2/v_1^2}\left|\frac{dU/v_1}{d\gamma}\right|\right]_n^{1/2}} \tag{56}$$

obtained by setting $d=z=H$ in equations (50)–(51) (i.e. assuming charge and receiver on bottom) is plotted as a function of γ in the first and second modes for case a in which $\rho_2/\rho_1=2.5,\alpha_2=\sqrt{3}\beta_2,\beta_2=3v_1$. The relative amplitudes of the Airy phases at the time $t=r/U_m$ have been computed for the same conditions and in the same units as G from the factor

$$A = \frac{r^{1/6}E(v)\Phi_1(k_n)\sin^2(\xi_n H)}{3^{2/3}\left[k/2\pi\right]_n^{1/2}\left[H^2/2\pi\left(\frac{dZ}{d\gamma}\right)\right]_n^{1/3}} \tag{57}$$

obtained from equation (52). The magnitudes of A for the cases $r=200H$ and $r=2000H$ have been computed and are plotted in Figure 10. Dispersion curves relating the frequency of waves with arrival time are given in Figures 4–6, so that amplitudes can be obtained as a function of frequency or travel time.

DISCUSSION OF THE NORMAL MODE SOLUTIONS

Whether the source is located within the liquid layer or the solid bottom, the dispersion in the normal mode solutions is identical and many of the character-

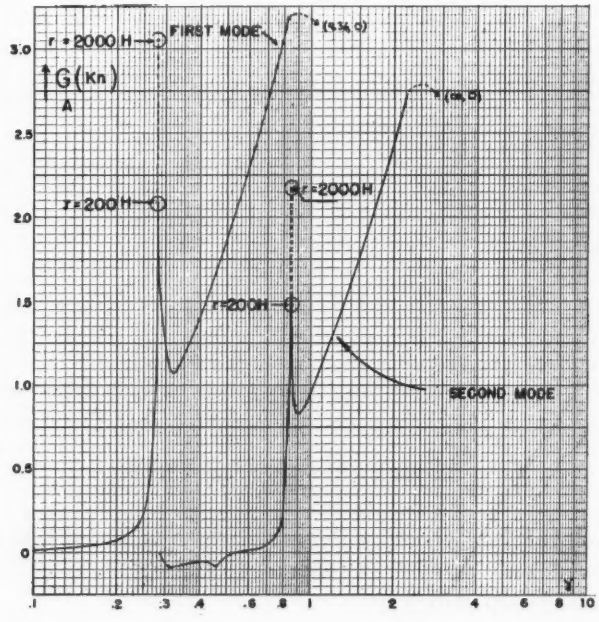

FIG. 10. Amplitude functions in the first and second mode for case a. The circled points give the amplitude of the Airy phases at the distances indicated.

istics of incoming signals for both problems are similar. The discussion given in an earlier paper which deals with a source within the bottom (Press, *et al.*) is in the large part applicable and will be repeated here with the slight modification required for a source located within the liquid layer.

In an earlier section the formal steady state solutions (26)–(29) were expressed as the sum of the residues of the integrands and two integrals along branch lines corresponding to the branch points $c=\alpha_2$ and $c=\beta_2$. The residues lead to the normal mode solutions which predominate at large distances because they diminish only as $r^{-1/2}$. Now the normal mode solutions vanish at $c=U=\beta_2$ and do not exist for $c>\beta_2$. In this region the branch line integrals contribute waves travelling with the speed of compressional and shear waves in the bottom, diminishing rapidly in amplitude with distance as $1/r^2$.

At a time $t>r/\beta_2$ after the initial impulse at the source (i.e. immediately after the arrival of shear waves) the normal mode contributions begin, gradually increasing in amplitude to become the predominant waves, providing r is large. The wave motion in the first two modes due to a distant impulsive point source of compressional waves having a moderately broad spectrum and located within the liquid layer can be obtained from Figure 10 as a function of frequency, and from Figures 4 and 10 as a function of arrival time. In the first mode the group velocity approaches the velocity of Rayleigh waves ($C_R=.9194\beta_2$) as $\gamma\to 0$. The first arrivals consist of low frequency Rayleigh waves whose amplitudes increase gradually from zero as the frequency increases from zero rapidly at first and then gradually. At the time $t=r/v_1$ a high frequency wave arrives travelling with the speed of sound in water. The group velocity and dispersion curves show an upper frequency limit for these waves. For frequencies above this limit the solutions reduce to boundary waves propagated along the interface in a manner analogous to Stoneley waves. According to Figures 4 and 10 the amplitudes of these waves are zero at $t=r/v_1$ ($\gamma=4.36$) but increase to large amplitudes shortly thereafter.

For $t>r/v_1$ the high frequency and low frequency branches of the group velocity curve contribute waves which arrive simultaneously and approach each other in frequency until they merge to form an Airy phase at a time corresponding to propagation at the minimum value of group velocity. The Airy phase amplitude of the first mode has been calculated from equation (56) and is plotted in Figure 10 for the two cases $r=200H$ and $r=2000H$. It is seen that Airy phase waves have large amplitudes relative to waves travelling at other values of group velocity, the amplitude of the Airy phase increasing with range as $r^{1/6}$ relative to waves traveling at other values of group velocity.

The second mode begins with waves arriving with a cut-off frequency at the time $t=r/\beta_2$. The amplitudes are zero at the onset and thereafter increase as the frequency increases. At the time $t=r/v_1$ high frequency waves ($\gamma\to\infty$) arrive travelling with the speed of sound in water. The amplitude of these waves is zero at the onset but increases rapidly thereafter. For $t>r/v_1$ the two arrivals corresponding to the low and high frequency branches of the group velocity curve of

this mode approach each other and merge at a minimum value of group velocity, producing the large amplitude waves of an Airy phase. The second mode Airy phase occurs at higher frequencies and has somewhat smaller amplitudes than that of the first mode.

It is to be noted that a maximum value of group velocity is present in the second mode. Ordinarily one might expect large amplitude waves to occur here, but the excitation function $\Phi_1(K)$ (Fig. 7) almost vanishes for the value of kH corresponding to this stationary value of group velocity and the resultant amplitudes show only a minor increase.

From equations (2), (3), (50), (51) it can be seen that the factor sin $(\xi_n z)$ gives the vertical variation of pressure and horizontal displacement and cos $(\xi_n z)$ gives the vertical variation of vertical displacement in the liquid layer. Similarly the factors $e^{-s_n(z-H)}$ $e^{-\eta_n(z-H)}$ give the vertical variation of stress and displacement in the bottom layer. Nodes of pressure correspond to antinodes of vertical displacement and vice versa. In Figure 8 the vertical variation in amplitude of pressure in the liquid layer is presented as a function of γ or the first two modes.

The wave motion at a point is obtained by the superposition of the contributions of all modes. Our discussion thus far has been limited to the first two modes. The frequencies of the higher modes corresponding to a given value of group velocity become progressively larger. In addition, the contributions of the high frequency higher modes will be cut down because of their greater susceptibility to scattering by an irregular bottom. It is only with a low pass receiver system however that a record uncomplicated by the contributions of the higher modes can be obtained. For a more detailed discussion of this point, the reader is referred to the paper of Pekeris (1948).

APPLICATION TO REFRACTION SHOOTING IN WATER COVERED AREAS

From the theory just presented a number of important conclusions can be drawn concerning the propagation of explosion sound over large ranges in water covered areas.

1) For solid bottoms, the amplitudes of waves travelling with the speed of compressional waves in the bottom will be relatively small. It is only after the arrival of the first shear waves that large amplitude waves appear. The shear waves begin with a limiting or cut-off frequency which is characteristic of the depth of water and the elastic constants of the bottom. For bottoms which can be treated as liquid, waves having appreciable amplitudes appear shortly after the arrival of the bottom compressional or ground waves. These ground waves begin with a cut-off frequency in a manner analogous to the shear waves of the solid bottom theory.

2) For a solid bottom a train of very low frequency waves ($\gamma \to 0$) travelling with the speed of Rayleigh waves in the bottom arrives. These waves increase in frequency and amplitude with increasing time. There is no analogous arrival in the liquid bottom theory.

3) For both the liquid and solid bottom theory a high frequency wave travelling with the speed of sound in water arrives riding on a low frequency "rider" wave. The frequency of the water waves shows a marked decrease with time. For the liquid bottom the amplitude of the water wave gradually increases with time. For the solid bottom the water waves rise to large amplitudes immediately after they arrive and then fall off somewhat.

4) For both the liquid and solid bottom theory the water waves and rider waves merge to form a train of waves of large amplitude which is known as an Airy phase. The frequency of the Airy phase is determined by the depth of water and the elastic structure of the bottom. The velocity of the Airy phase depends only on the elastic constants in the bottom.

5) The response of a hydrophone sensitive to pressure changes and a geophone sensitive to the vertical velocity of a water particle will vary with depth because of the vertical standing wave pattern shown in Figure 8. For any given mode and frequency the ideal location of a hydrophone is at a pressure antinode and the ideal location of a geophone is at an antinode of vertical displacement. Antinodes and nodes for pressure correspond respectively to nodes and antinodes for vertical displacement (or velocity). With the use of curves such as those of Figure 8 the vertical location of a receiver for peak response at a given frequency can readily be obtained.

In all water covered areas where refraction shooting is undertaken, layering in the bottom occurs and our assumption of an unstratified bottom is indeed an over-simplification. If the thickness of the first bottom layer is of the order of several times the water depth, the above theory should be applicable to a fair degree of approximation.

ACKNOWLEDGMENT

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PULSE PROPAGATION IN TWO SPACIAL DIMENSIONS*

C. HEWITT DIX†

ABSTRACT

Mathematicians have known for many years that two dimensional wave propagation is very different from one (plane) or three (spherical) dimensional propagation. Plane and spherical pulses can be propagated without change of form—an impossibility for cylindrical waves.

The object of the present paper is to clarify the physical picture involved. It is shown that for any initially given axially symmetric disturbance, confined between two concentric circular cylinders, *if* energy is subsequently transmitted outwards *then* it is also always subsequently transmitted inwards. The only possible case of no inward transmission is that of no transmission. Thus for a two dimensional pulse propagation every part of the pulse is being continually split at each instant, part traveling inwards and part outwards. Only the very simplest problem is solved in this paper. However the process of tail (coda) formation is now clear for this case.

INTRODUCTION

The propagation of seismic pulses is, in actual cases, a process of such detailed complication that we cannot hope to come very close to an adequate theoretical account of many minor properties. Only the grosser aspects may be understood at this stage of development. Thus we consider a homogeneous infinite elastic medium and hope that our understanding of this case will help us to understand some actual cases in their rougher aspects.

The theory of plane and spherical pulses is well worked out and we tend to picture most of the processes that can occur in terms of these two special cases. The picture we use from the plane pulse case is that of a pulse traveling in one direction with a characteristic velocity without change of form. The picture we use from the spherical pulse case is that of a pulse traveling outwards with a characteristic shape. This shape is only slightly modified as the distance from the center varies. In both cases energy is transmitted only outward, or in one direction.

The cases of the plane and spherical pulses are very important, but also very special. The intensity over the whole pulse surface is constant; what if this intensity should vary? The principal radii of curvature of the pulse front surface are the same; what if they should be different? It is this latter question that we discuss in the present note.

We shall discuss the problem of the propagation of a cylindrical pulse as the simplest case in which the curvatures of the pulse front surface are not equal. In this case the pulse changes its form in a most serious manner and an attempt to make the pulse travel only outwards completely removes the pulse. In other

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words the physical picture that we obtain from the cases of plane and spherical pulses must be severely limited.

The purpose of this paper is then to warn against extending the picture of the plane or spherical pulse transmission to other cases by direct assumption of applicability without proof. It is not asserted that these simple pictures are never applicable; only that they should be applied with proof of their applicability or with a full understanding that an unjustified assumption is being used that may make the whole resulting theory seriously in error.

Cylindrical waves have been extensively studied in the literature so that the present note cannot add much to what is already well known. But after Volterra (1894) found that an outward traveling pulse of fixed form is not possible for a cylindrical wave, it still remained possible that the initial conditions might be so given that, although the pulse shape has to change, energy may be transmitted only outward. Volterra also gave a formula which can be used to calculate the way in which a pulse changes its shape in any particular case. Probably Volterra's formula can be used to establish the result of the present note but the author was not successful in his attempts in this direction.

The object of the present note is to obtain a *physical picture* applicable to cylindrical pulse propagation. This objective is different from that of finding a mathematical formula to represent the process which Volterra has accomplished. These remarks are needed as a bit of mathematics has to be used and some readers might suppose that the objective is mathematical, whereas the mathematics is only a necessary tool.

The conclusion that we reach is the following: any initially limited cylindrical pulse always spreads outwards and always contracts inwards with the same velocity; this applies to each part of the pulse and to each subsequent time however near or remote. Thus a pulse initially limited must lengthen with a velocity $2V$.

Attempts have been made (Baker and Copson, 1939; Hadamard, 1923) to describe this process as a "diffusion." But "diffusion" is a definite physical process satisfied by an equation involving the first derivative in the time and the velocity of spread is infinite. The term "diffusion" may therefore be easily misused.

Mathematical Proof of the Principle

The differential equation of an elastic compressional cylindrical pulse is the same as that for a vibrating circular membrane, so we shall refer to the membrane directly. This differential equation is

$$\frac{\partial^2 w}{\partial r^2} + \frac{1}{r}\frac{\partial w}{\partial r} - \frac{1}{V^2}\frac{\partial^2 w}{\partial t^2} = 0, \tag{1}$$

where r is the radial distance from the center of the cylindrical pulse or from the center of the membrane, t is the time, V is the velocity of wave propagation, and w is the dilatation of the cylindrical pulse or the normal displacement of the membrane. Equation (1) is to be solved subject to the initial conditions,

$$w(r, o) \equiv w_0(r) \quad \text{and} \quad (\partial w(r, t)/\partial t)_{t=0} \equiv w_1(r). \tag{2}$$

These initial conditions will always be selected so that $w_0(r) \equiv w_1(r) \equiv o$ excepting within a ring $o < r_1 < r < r_2$, thus the pulse is always initially limited in length. The above problem is solvable by the "method of Riemann" (Bateman, 1944; Darboux, 1889). Both to apply the "method" and for our subsequent argument it is necessary to make a transformation of coordinates, $x = (Vt + r)(2)^{-1/2}$, $y = (Vt - r)(2)^{-1/2}$, which carries equation (1) over to

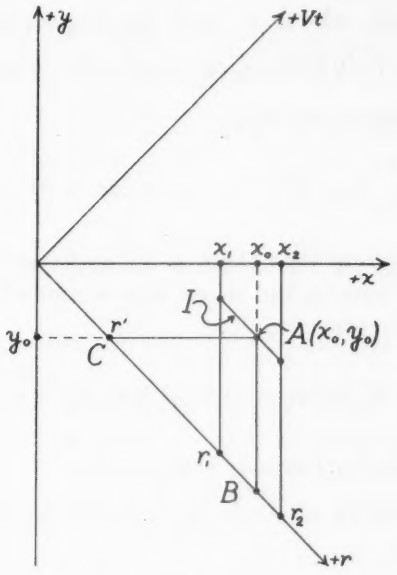

FIG. 1

$$\frac{\partial^2 w}{\partial x \partial y} - \frac{1/2}{(x - y)} \frac{\partial w}{\partial x} + \frac{1/2}{(x - y)} \frac{\partial w}{\partial y} = o \tag{3}$$

which has an adjoint (Darboux, 1889)

$$\frac{\partial^2 v}{\partial x \partial y} + \frac{1/2}{(x - y)} \frac{\partial v}{\partial x} - \frac{1/2}{(x - y)} \frac{\partial v}{\partial y} - \frac{1}{(x - y)^2} v = o. \tag{3^1}$$

Then referring to Figure 1 the fundamental formula of Riemann is

$$w(A) \cdot v(A) = \{w(B) \cdot v(B) + w(C) \cdot v(C)\}/2 - \int_C^B \{N dx - M dy\} \tag{4}$$

where

$$\left.\begin{aligned} M &= -\frac{w \cdot v}{2(x - y)} + \frac{1}{2}\left(v \cdot \frac{\partial w}{\partial y} - w \cdot \frac{\partial v}{\partial y}\right) \\ N &= +\frac{w \cdot v}{2(x - y)} + \frac{1}{2}\left(v \cdot \frac{\partial w}{\partial x} - w \cdot \frac{\partial v}{\partial x}\right) \end{aligned}\right\}. \tag{5}$$

But the integral in equation (4) is taken along the line $Vt=0$ where $dx=-dy$ so this integral becomes

$$-\int_C^B \{N+M\}dx = -\frac{1}{2}\int_C^B \left\{v\left(\frac{\partial w}{\partial x}+\frac{\partial w}{\partial y}\right)-\left(\frac{\partial v}{\partial x}+\frac{\partial v}{\partial y}\right)w\right\}dx. \quad (6)$$

Since on BC, $t=0$, $w(r, 0)=w_0(r)$ and $\partial w/\partial x+\partial w/\partial y=(2/V^2)^{1/2}(\partial w/\partial t)_{t=0}$

$$\partial w/\partial x+\partial w/\partial y=(2/V^2)^{1/2}(\partial w/\partial t)_{t=0}=(2/V^2)^{1/2}w_1(r),$$

$=(2/V^2)^{1/2}w_1(r)$, the integral becomes

$$-(1/2)\int_C^B \{v(2/V^2)^{1/2}w_1-(\partial v/\partial x+\partial v/\partial y)w_0\}dx. \quad (7)$$

We shall assume tentatively that there is no backward transmission, so that $w(A)=0$. As we assume both w_0 and w_1 are zero outside of $r_1<r<r_2$, $w(c)=w_0(r')=0$. Hence equation (4) reduces to

$$\int_C^B \{(\partial v/\partial x+\partial v/\partial y)w_0-(2/V^2)^{1/2}vw_1\}dx+v(B)w_0(B)=0. \quad (8)$$

The required v is given by Darboux (1889) and is

$$v(x, y; x_0, y_0)=(x-y)(x-y_0)^{-1/2}(x_0-y)^{-1/2}F(1/2, 1/2; 1; \sigma) \quad (9)$$

where

$$\sigma=\{(x-x_0)(y-y_0)\}/\{(x-y_0)(y-x_0)\} \quad (10)$$

and F is the hypergeometric function.

We may note that

$$v(B)\equiv v(x_0, -x_0; x_0, y_0)=(2x_0/(x_0-y_0))^{1/2}, \quad (11)$$

so that $v(B)$ is never zero (since y_0 is negative and bounded). Hence we may divide equation (8) through by $v(B)$. Also we may show that

$$(\partial v/\partial x+\partial v/\partial y)_{y=-x}$$

$$=\frac{-x(x_0+y_0)}{(x-y_0)^{3/2}(x+x_0)^{3/2}}F\left(\frac{1}{2}, \frac{1}{2}; 1; \sigma\right)$$

$$+\frac{4x^2(x_0+y_0)(x_0-y_0)}{(x-y_0)^{5/2}(x+x_0)^{5/2}}F'\left(\frac{1}{2}, \frac{1}{2}; 1; \sigma\right)$$

$$=\frac{-x(x_0+y_0)}{(x-y_0)^{3/2}(x+x_0)^{3/2}}\left\{F\left(\frac{1}{2}, \frac{1}{2}; 1; \sigma\right)\right.$$

$$\left.-\frac{x(x_0-y_0)}{(x-y_0)(x+x_0)}F\left(\frac{3}{2}, \frac{3}{2}; 2; \sigma\right)\right\}. \quad (12)$$

Making use of equations (9), (11), and (12) we can rewrite equation (8) in the more explicit form

$$\int_C^B \frac{-(x_0 - y_0)^{1/2}(x_0 + y_0)x}{(2x_0)^{1/2}(x - y_0)^{3/2}(x + x_0)^{3/2}} \left\{ F\left(\frac{1}{2}, \frac{1}{2}; 1; \sigma\right) - \frac{x(x_0 - y_0)}{(x - y_0)(x + x_0)} F\left(\frac{3}{2}, \frac{3}{2}; 2; \sigma\right) \right\} w_0(x)dx + w_0(x_0)$$

$$= \int_C^B \frac{2x(x_0 - y_0)^{1/2}}{\sqrt{x_0}^{1/2}(x - y_0)^{1/2}(x + x_0)^{1/2}} F\left(\frac{1}{2}, \frac{1}{2}; 1; \sigma\right) w_1(x)dx \qquad (13)$$

or more shortly

$$\int_{x_1}^{x_0} K_0(x_0, x)w_0(x)dx + w_0(x_0) = \int_{x_1}^{x_0} K_1(x_0, x)w_1(x)dx. \qquad (14)$$

Thus we may regard equation (14) as a Volterra integral equation of the second kind for $w_0(x)$, for each $w_1(x)$.

We express the solution of equation (14), for $w_0(x_0)$, in the usual way (Volterra and Peres, 1936), in terms of the resolvent kernel $S_0(x_0, x)$ for $K_0(x_0, x)$, thus,

$$w_0(x_0) = \int_{x_1}^{x_0} K_1(x_0, x)w_1(x)dx + \int_{x_1}^{x_0} \left[\int_{x_1}^{s} K_1(s, \zeta)w_1(\zeta)d\zeta \right] S_0(x_0, s)ds$$

$$= \int_{x_1}^{x_0} \left\{ K_1(x_0, x) + \int_x^{x_0} S_0(x_0, s)K_1(s, x)ds \right\} w_1(x)dx. \qquad (15)$$

So far we have only required that $w(A) = 0$. It would be a natural next step to require also that $\partial w(A)/\partial t = 0$ for all A in the interval, I, see Figure 1. But this leads to an integro-differential equation which appears to the writer to introduce unnecessary complication into the problem. To avoid this difficulty we make use of the following—

LEMMA.—Given the general conditions of the problem, *if* $w \equiv 0$ on I_i, called an "initial" interval, see Figure 2, *then* $w \equiv 0$ on I_l, called a "later" interval, *implies and is implied by* $\partial w/\partial t \equiv 0$ on I_i. That $w \equiv 0$ and $\partial w/\partial t \equiv 0$ on I_i implies $w \equiv 0$ on I_l is a trivial application of equation (4) where BC includes part of I_i. To show the converse, form a relation similar to equation (8) where $w \equiv 0$ on I_i, where the initial data occur, so the result is

$$\int_{x_1}^{x_0} v \cdot w_1 dx = 0 \qquad (16)$$

and $v \neq 0$ so the only solution of equation (16) is $w_1(x) = 0$ for $x_1 \leqq x \leqq x_2$.

We are now ready to proceed with the process of proof. This may be accomplished by dividing the interval from r_1 to r_2 into n little intervals. We then work first with the inner interval from r_1 to $r_1 + \Delta r$ to show that no backward transmis-

sion for this part implies both $w_1(r) \equiv 0$ and $w_0(r) \equiv 0$ for this part. It is a property of the proof for the inner part, that if $\Delta r = (r_2 - r_1)/n = \text{constant}$ for each part, then the inequalities used in the proof for the inner part hold with even greater accuracy for the outer parts. Thus the proof is established for all parts. However one has to use very close approximations which make the details of the calculations very long and involved.

Rather than carry through the details which would extend the paper unnecessarily we present the proof for a special case. This special case will later be seen to be quite general so that the proof will be entirely rigorous after all.

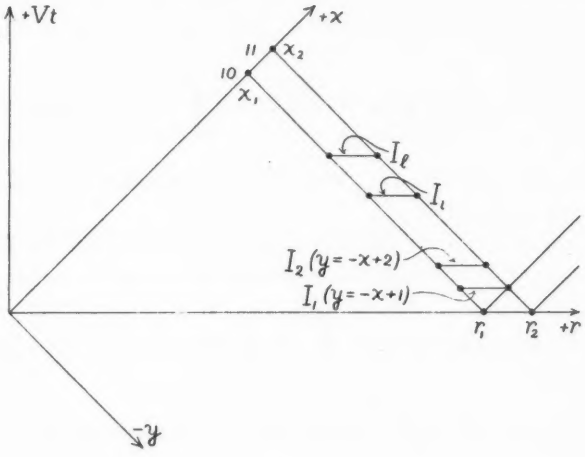

FIG. 2

We have taken $r_1 = 10(2)^{1/2}$ and $r_2 = 11(2)^{1/2}$. I_1 is $y = -x+1 (10 \leqq x \leqq 11)$ and I_2 is $y = -x+2$ $(10 \leqq x \leqq 11)$, see Figure 2. Equation (15) is formed for I_1 and for I_2 and the difference of the two resulting equations gives

$$\int_{x_1}^{x_0} \left[\left\{ K_{12}(x_0, x) + \int_x^{x_0} S_{02}(x_0, s) K_{12}(s, x) ds \right\} - \left\{ K_{11}(x_0, x) + \int_x^{x_0} S_{01}(x_0, s) K_{11}(s, x) ds \right\} \right] w_1(x) dx$$

$$\equiv \int_{x_1}^{x_0} \Phi_{1,2}(x_0, x) w_1(x) dx = 0, \tag{17}$$

where the $K_{11} \equiv K_1$ and $S_{01} \equiv S_0$ for A on I_1 and $K_{12} \equiv K_1$ and $S_{02} \equiv S_0$ for A on I_2. Since $\Phi_{1,2}(x_0, x_0) \equiv 0$, the usual procedure (Volterra and Peres, 1936), would be to differentiate equation (17) with respect to x_0 until a non-vanishing term is obtained outside of the integral sign. This can be done but the numerical verification which follows is sufficient for our purposes and shows very clearly that other

zeros of $\Phi_{1,2}(x_0, x)$ will not cause us trouble. Quite evidently the velocity, V, enters homogeneously into equation (17) and so is without influence on the result.

Numerical values of K_{01}, S_{01}, K_{11}, K_{02}, S_{02}, K_{12} and $\Phi_{1,2}$ were calculated using a 0.2 interval over the range $10 \leqq x \leqq x_0 \leqq 11$. Gregory's formula (Whittaker and Robinson, 1924), was used in the numerical integration. Table I gives the main

x_0	x	$-K_{01} \times 10^4$	$S_{01} \times 10^4$	K_{11}	$-K_{02} \times 10^4$	$S_{02} \times 10^4$	K_{12}	$\Phi_{1,2}$
10.0	10.0	6.578,947	6.578,947	1.000,000,000,0	13.888,889	13.888,889	1.000,000,000,0	0.000,000,000
10.2	10.0	6.382,778	6.382,777	.990,249,643,0	13.467,912	13.467,876	.990,389,831,6	0.000,280,411
	10.2	6.316,960	6.316,960	1.000,000,000,0	13.320,546	13.320,546	1.000,000,000,0	0.000,000,000
10.4	10.0	6.194,758	6.194,756	.980,729,298,1	13.064,650	13.064,581	.980,998,343,1	0.000,538,194
	10.2	6.132,274	6.132,273	.990,436,030,7	12.924,812	12.924,778	.990,570,460,0	0.000,267,612
	10.4	6.070,319	6.070,319	1.000,000,000,0	12.786,416	12.786,416	1.000,000,000,0	0.000,000,000
10.6	10.0	6.014,452	6.014,449	.971,430,160,3	12.678,146	12.678,046	.971,817,688,2	0.000,775,275
	10.2	5.955,116	5.955,115	.981,093,511,0	12.545,406	12.545,342	.981,351,719,0	0.000,516,512
	10.4	5.896,240	5.896,239	.990,615,431,7	12.413,944	12.413,933	.990,744,450,2	0.000,258,076
	10.6	5.837,848	5.837,848	1.000,000,000,0	12.283,805	12.283,805	1.000,000,000,0	0.000,000,000
10.8	10.0	5.841,450	5.841,448	.962,343,890,5	12.307,504	12.307,378	.962,840,393,9	0.000,993,372
	10.2	5.785,088	5.785,085	.971,964,112,9	12.181,463	12.181,371	.972,336,331,8	0.000,744,640
	10.4	5.729,121	5.729,120	.981,444,217,9	12.056,548	12.056,488	.981,692,230,2	0.000,496,134
	10.6	5.673,578	5.673,577	.990,788,229,9	11.932,807	11.932,778	.990,912,156,9	0.000,247,881
	10.8	5.618,483	5.618,483	1.000,000,000,0	11.810,280	11.810,280	1.000,000,000,0	0.000,000,000
11.0	10.0	5.675,373	5.675,369	.953,462,588,3	11.951,890	11.951,740	.954,059,342,2	0.001,194,045
	10.2	5.621,818	5.621,816	.963,039,942,6	11.832,172	11.832,056	.963,517,204,1	0.000,954,861
	10.4	5.568,603	5.568,601	.972,478,474,0	11.713,442	11.713,357	.972,836,273,7	0.000,715,787
	10.6	5.515,754	5.515,753	.981,782,154,8	11.595,748	11.595,693	.982,020,565,4	0.000,476,903
	10.8	5.463,298	5.463,297	.990,954,783,4	11.479,136	11.479,109	.991,074,012,0	0.000,238,486
	11.0	5.411,255	5.411,255	1.000,000,000,0	11.363,636	11.363,636	1.000,000,000,0	0.000,000,000

TABLE I

results and is given more completely than is required for the present purpose as K_0 and K_1 may prove useful for the calculation of $w(A)$ given w_0 and w_1. Aside from the difference in sign, K_0 differs very little from S_0 so that only S_0 is represented in Figure 3. K_{11} and K_{12} are shown on the same graph to emphasize their similarity. $\Phi_{1,2}$ is also graphed.

An inspection of Figure 3 shows clearly the non-vanishing character of $\Phi_{1,2}$ except at $x = x_0$. Perhaps the simplest solution of equation (17) is to regard it as the limit of sequences of finite sums such as those employed by Volterra in his treatments of the problems of this genus (Volterra and Peres, 1936). We thus find $w_1 = 0$ for an everywhere dense set of points on $10 \leqq x \leqq 11$. If we assume w_1 is continuous then $w_1 \equiv 0$ for $10 \leqq x \leqq 11$. Substituting $w_1 \equiv 0$ in equation (15) we obtain $w_0 \equiv 0$ for $10 \leqq x \leqq 11$. Thus, among the class of continuous functions $w_0(x), w_1(x)$ the only pair which gives rise to no inward transmission of energy is identically zero and so gives rise to no transmission of energy at all.

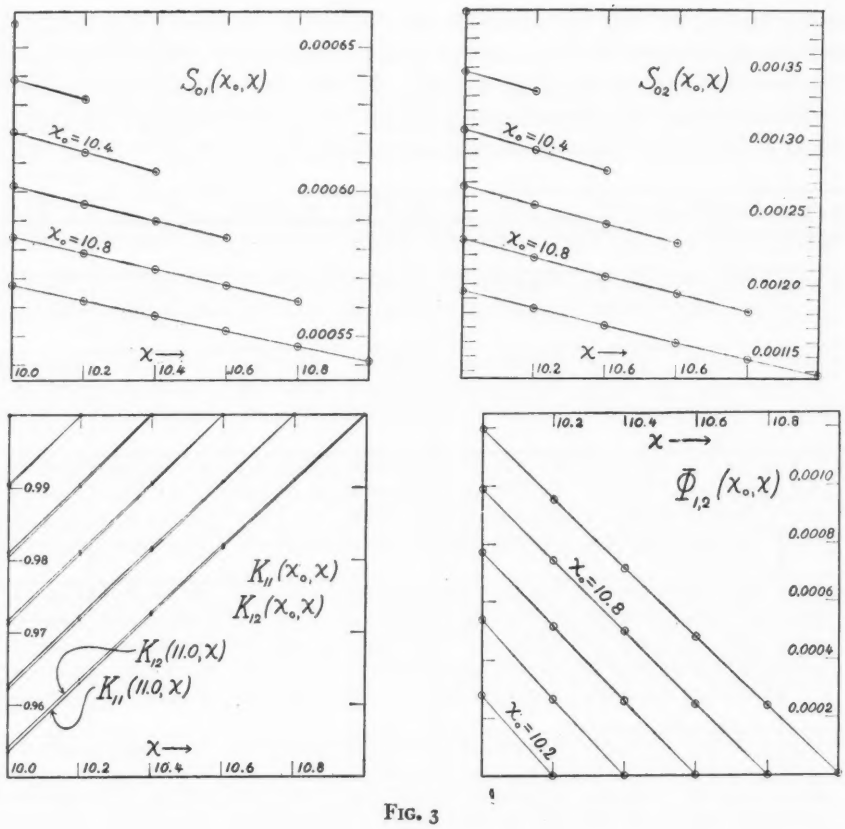

FIG. 3

Let us now return to the more general case where our interval is from r_1 to r_2 with $0<r_1<r_2$. If $r_2-r_1=r_1/10$ then we can transfer every step of the above argument to this case by a mere change of scale. The same remark can be made if $r_2-r_1<r_1/10$. If $r_2-r_1>r_1/10$ then the interval can be divided into n equal intervals such that $(r_2-r_1)/n \leqq r_1/10$ and the above argument applied with the suitable expansion or contraction of scale.

The proof of our principle is therefore complete.

CONCLUDING REMARKS

It will be instructive to consider a few applications. In the theory of the reflection and refraction of plane pulses, use is made of the assumption that the secondary pulses are all transmitted away from the interface. These secondary waves are limited by the interface and so are not strictly infinite plane waves. However it may be shown that the assumption of outward transmission that is made leads to a steady state system which is consistent with the principles of mechanics and so certainly represents a possible state of motion. Thus the hy-

pothesis of no backward transmission is justified in this case. But the assumption was made without justification.

Consider the case of a point source buried in a semi-infinite medium. The theory has been formulated by many authors (Lamb, 1904; Cagniard, 1939), for the steady state and for the pulse problems. The steady state formulation contains a serious ambiguity—are Rayleigh Waves to be included or not? One may impose an additional "condition" the so-called "*Sommerfeld Ausstrahlungsbedingung*" that

$$\lim_{r\to\infty} r\left(\frac{\partial\phi}{\partial r} - ik\phi\right) = 0$$

where $k = 2\pi \times$ frequency/velocity. Such a "condition" does make the solution unique in certain cases (Kahan and Eckart, 1949; Epstein, 1947), but does eliminate the surface wave. Such an elimination may or may not be a satisfactory result, but the "condition" itself may be doubted so the result of its use has also to be doubted, at least until the "condition" has been proven.

Rayleigh waves and Love waves travel with certain velocities. Can the propagation of these waves be altogether outwards? A host of problems are proposed by the above considerations. The possibilities for mathematical generalization are extensive and important.

Naturally the above discussion is not limited to seismic waves or membrane waves but applies as well to waves in fluids, electromagnetic waves, the waves of wave mechanics (de Broglie), etc. The only requirement is that equation (1) be satisfied.

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CRYSTAL SHAKETABLE FOR GEOPHONE STUDIES*

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ABSTRACT

A comparison is made between shaketables driven by piezoelectric crystals and those of conventional design. The general construction of crystal shaketables and the auxiliary equipment necessary for geophone studies are discussed. The theory of geophone motion shows that a measurement of phase shift between the geophone output and the crystal shaketable driving voltage can be used to determine the natural frequency and damping of the moving mass of the geophone. The crystal shaketable gives a simple method for routine testing of geophones both in the laboratory and the field.

The ideal geophone is an instrument which converts the motions of the surface of the earth into electrical signals which can be amplified, filtered, and recorded. Most geophones can be represented by a mass supported elastically to a case which is in contact with the ground. Generally, restraining members are included in the geophone to restrict the motion of the mass to one direction. In addition, damping is generally provided to make the geophone respond in a desirable manner. The relative motion between the mass and the case is converted into an electrical voltage which can be made proportional to either the relative displacement, relative velocity, or relative acceleration.

An ideal geophone, which can be represented as a mass elastically supported to the case, will have two characteristics which completely determine the mechanical behavior of the system: the natural frequency of oscillation of the mass and the damping coefficient. The restraining members, which confine the motion to one direction, generally introduce secondary modes of oscillation. By proper design, the effect of the secondary modes can be made small and to occur at frequencies different from the frequencies measured by the geophone. In the use of the seismic method for geological exploration, geophones must be portable, and since a large number are used simultaneously, they must respond alike within certain tolerances. The motion of the earth which is applied to the geophone is of the order of 10^{-6} inches.

The purpose of a shaketable for geophone studies is to determine the sensitivity, the natural frequency, and damping of the geophone, and to prove that secondary modes of oscillation do not affect the behavior of the geophone at frequencies of oscillation of the earth's surface which are found useful in seismic exploration. The device should be simple, so that a large number of geophones can easily be compared. In addition, these comparisons should be made for amplitudes of case motion comparable to those found in use, i.e., about 10^{-6} inches.

The conventional shaketables, which have been discussed in the literature previously, are large and require special auxiliary driving equipment. They re-

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quire a relatively large driving power and generally move the geophone case through considerably larger amplitudes of motion than 10^{-6} inches. It is necessary to calibrate the device to find the true relationship between driving voltage and table motion.

In order to overcome the inherent disadvantages of the conventional types of shaketables, a study was made to determine the possibilities of using piezoelectric crystals as a transducer to convert electrical voltage into mechanical motion. This study showed that a shaketable could be built which would be small in size,

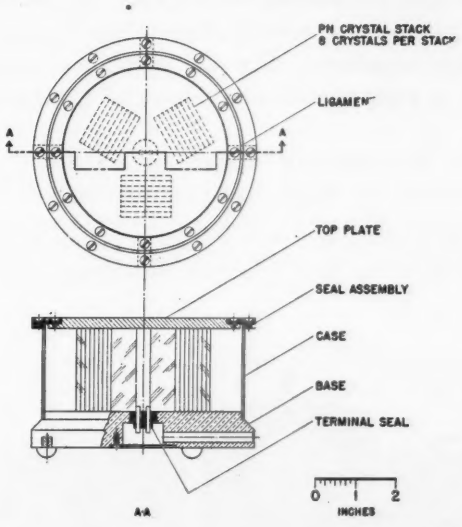

FIG. 1. Assembly drawing of PN crystal shaketable.

give accurate reproduction of voltage for motions as small as 10^{-8} inches, require very little power, and be simple to calibrate. Piezoelectric crystals are very stiff so that the effects of the masses of the geophone and crystal base on the crystal produce resonance points at frequencies above 300 cps. The peak displacement along the crystal axis is directly proportional to the peak voltage from DC to frequencies near the resonance points. Various crystal materials were considered, and the first experimental table was built out of Rochelle salt slabs. The sensitivity of the table was found to be about 6.6×10^{-8} inches/volt. Rochelle salt is weak mechanically and will break down under temperature conditions encountered in field operations, so that it was felt that a shaketable using Rochelle salt would not be suitable for field use. PN or ADP (ammonium-dihydrogen phosphate) is a piezoelectric material which was developed during the war. This material is less sensitive than Rochelle salt but is stronger mechanically and will withstand field temperatures.

Consultation with engineers from The Brush Development Company indicated that the ADP crystal shaketables could be built, so the design shown in

Figure 1 was made. Gulf built the cases, and Brush installed the crystals and sealed the cases. A movable plate to set the geophone on is supported by three stacks of crystals with eight crystals in parallel in each stack. A housing on a heavy base allows the crystal assembly to be hermetically sealed by the rubber diaphragm without restricting the motion of the table top. The leads to the crystals, all wired in parallel, are brought out through a seal as shown. Three pads allow the shaketable assembly to balance on a rigid base which preferably should weigh much more than the geophone. Shaketables built according to this design were found to have a sensitivity of 0.8×10^{-8} inches per volt.

The power required to drive crystal shaketables is small, since the crystals have a relatively high impedance. The d.c. resistance (largely leakage) of the three parallel stacks is greater than one megohm. The capacities at 1,000 cps. are:

Rochelle Salt 0.0020 microfarads
ADP 0.0021 microfarads

It has been found that an oscillator with a high impedance push-pull output of 25 volts is sufficient to drive the Rochelle Salt Shaketable and 180 volts the ADP Shaketable.

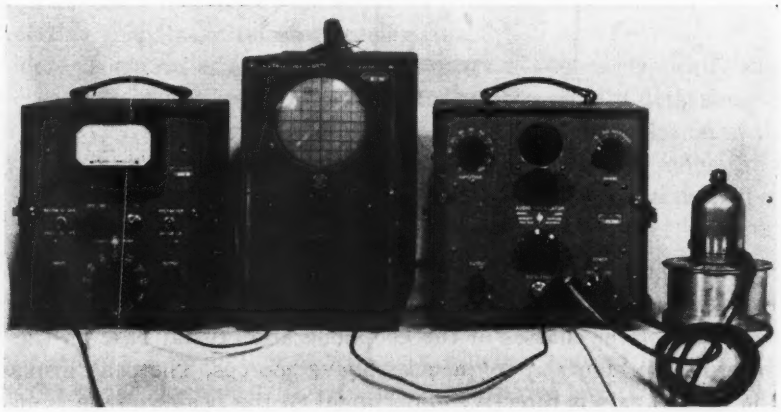

FIG. 2. Test setup for geophone calibrations.

Figure 2 shows the complete test setup for geophone calibrations. An oscillator was modified to give a high-voltage, high-impedance output voltage up to 180 volts undistorted. This voltage drives the shaketable at displacements up to 2×10^{-6} inches R.M.S. at the oscillator frequency with the displacement in phase with the driving voltage. This same voltage is put on the horizontal amplifier of the oscilloscope. The geophone under test is placed on the shaketable, and its output goes to the voltmeter amplifier (free from phase shifts) and to the vertical amplifier of the oscilloscope. The sensitivity of the detector can be measured by the voltmeter. In many places the inherent noise level from machinery, etc., may

be greater than the shaketable amplitude. In these places, a simple shockmounted plate can be used as a base for the shaketable. This plate should weigh considerably more than the geophone being studied.

The natural frequency and damping can be determined from the phase relationship determined by the oscilloscope pattern and the oscillator frequency. This phase is a function of the ratio of the major-to-minor axes of the ellipse found on the oscilloscope screen, when equal amplitudes of voltage are impressed on the screen.

Ratio	*Phase Shift*
Infinite	0°
20	6°
4	28°
2	53°
1	90°

For dynamic geophones, the natural frequency of the geophone is the oscillator frequency which gives a straight-line pattern (zero phase shift).

The dynamic equation of motion for most geophones is well known and given by:

$$\ddot{x} + \frac{C}{M}\dot{x} + \frac{S}{M}x = m\ddot{y}, \tag{1}$$

where

x is the displacement of the mass with respect to the case,
y is the displacement of the case,
C is the damping constant,
S is the restoring constant,
M is the suspended mass,

If:

$w_0 = 2\pi f_0$,
$w_0^2 = S/M$,
$2hw_0 = C/M$,
f_0 is the natural frequency,
h is the damping coefficient i.e., the ratio of actual damping to critical damping,

Equation (1) becomes,

$$\ddot{x} + 2hw_e\dot{x} + w^2{}_0x = m\ddot{y},$$

if f = driving frequency,
$w = 2\pi f$,
$y = y_0 \cos wt$,
$x = A \cos (wt+a)$, displacement,
$-\dot{x} = Aw \cos [wt+a-(\pi/2)]$, velocity,
$-\ddot{x} = Aw^2 \cos (wt+a)$, acceleration,

then

$$A = (my_0)(w^2/w_0^2)/\sqrt{(1 - w^2/w_0^2)^2 + (4h^2)(w^2/w_0^2)}$$

$$\tan a = (2h)(w/w_0)/(w^2/w_0^2) - 1$$

In a displacement or acceleration-type geophone, the phase between the output voltage and the driving displacement can be represented by the angle "a." In a velocity-type geophone, the phase is given the angle $a-(\pi/2)$.

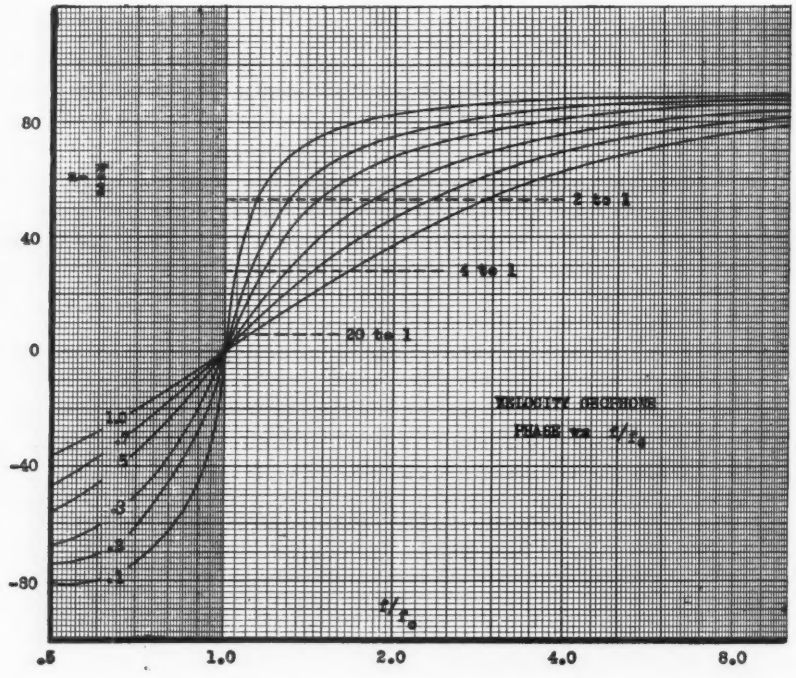

FIG. 3. Phase function for velocity-type geophone.

In Figure 3, the family of curves shows the phase angle, $a-(\pi/2)$, as a function of f/f_0 for various values of damping coefficient "h." It will be observed that zero phase shift occurs at $f/f_0 = 1$ for all values of damping. Thus to determine the natural frequency of a velocity-type geophone, the geophone is tested in the setup shown in Figure 2, and the frequency for zero phase shift is determined. The per cent error of the frequency determination depends on the damping and approaches zero as the damping approaches zero. For a geophone with 0.7 of critical damping an error of less than 7 per cent is easily obtained in determining the natural frequency. This can be seen by examining the phase curves. The dashed curves, represent given ratios of major-to-minor axis of the pattern on the oscilloscope. Ratios greater than 20-to-1 are easy to read even on a two inch screen. Thus the

phase error is less than 6° and frequency error less than 10 per cent for critical damping and 1.5 per cent for 0.1 critical damping.

The damping of a geophone is determined by observing the frequency for a given phase shift (ratio of major-to-minor axes on the oscilloscope). Thus for a 0.5 critical, the 4-to-1 ratio occurs at a frequency 29 per cent above the natural frequency and for a 0.7 critical at a frequency 43 per cent above the natural. The study of geophones for secondary modes of vibration can be made by observing the amplitude of the response as a function of frequency. A continually increasing amplitude (without humps) indicates that the secondary modes are of negligible importance.

The equipment necessary for geophone studies and calibrations in the field can be made in such a manner that parts can be used separately for other field purposes. For trouble shooting in amplifiers, an oscillator, AC voltmeter, and oscilloscope are very useful. Thus, the only additional piece of equipment necessary is the crystal shaketable itself. The test equipment and procedure then can be made identical to that which has been described above.

FAULT INTERPRETATION FROM SEISMIC DATA IN SOUTHWEST TEXAS*

MILLER QUARLES, JR.†

ABSTRACT

Many of the oil-bearing structures around the Gulf Coast and in Southwest Texas are found along a distinctive type of low-angle normal faulting. Reflection sesimograph shooting across the faults gives normal information on the downthrown side but produces two types of distorted and misleading data below the fault plane on the upthrown side. One type of distortion gives a time lag up to 100 milliseconds to reflections plotted vertically below the upper limit of the fault plane. If this time lag is not recognized, the fault may be located as far as a mile from its true position.

The second type of distortion below the fault plane is an apparent increase in dip toward the fault plane in the deeper beds. The magnitude may be great enough to cause some reflecting horizons on the upthrown side of the fault to be plotted actually deeper than those on the downthrown side. This could readily cause error in locating the fault and determining the magnitude and direction of throw.

The first "drop" type of distortion is explained by a refraction pattern downward *along* a portion of the fault plane before the energy is reflected back from the recognized interface. The second "increased dip" type of distortion may be either a reflection time lag through the gouge zone of the fault or a refraction *across* the fault plane and a reflection from the known interface.

INTRODUCTION

The data presented in this paper was compiled as a result of nearly four years' work for Magnolia Petroleum Company in Southwest Texas with a United Geophysical seismograph crew, looking primarily for fault structures. Over a hundred separate faults were found and most of them were mapped continuously for miles along their traces. One fault was followed for nearly fifty miles and was crossed at thirty-eight places by seismograph lines. The record quality in general was excellent and reflection character was good enough to permit a reliable correlation across faults and an accurate estimate of the amount of throw. This wealth of good material, studied continuously and checked at several places by drilling, has made it possible to separate reliable data from abnormal and to classify several distinctive fault patterns. Seventeen cross sections have been selected to illustrate the interpretation technique used and the ideas involved.

GEOLOGY

The work was done in the southern portion of the thick series of Gulfward dipping Tertiary sediments known as the Coastal Plains. The stratigraphic section is composed of thick shales and sands of Eocene and younger ages. No pronounced angular unconformities have been mapped.

The faults are all low angle normal with throws ranging from a few feet to over 1,000 feet. Most of the fault plane angles of dip are from 45 to 60 degrees with a few shallower and a few steeper. Their strikes in general parallel the Gulf Coast. The downthrown side of the fault is usually but not always towards the

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Gulf. Three of the rarer up-to-the-coast fault sections are shown in this report in Figures 1, 3 and 11.* Some of the faults are accompanied by adjustment faults as is seen on Figure 3 and is suggested on several others. The faults may die out in a short space both laterally and vertically. The fault on Figure 10 has 900 feet of throw at a depth of 7,500 feet but dies out completely before it reaches a horizon 1,500 feet deep. Short spur faults may be present.

A very important characteristic of many of the faults is the dipping down of beds into the downthrown side of the fault and possibly dipping up into the upthrown side, giving the appearance of reverse drag (Fig. 12). Oil may accumulate on either side of such a fault, on the anticline off the downthrown side and against the fault on the upthrown side. Oil may also accumulate on the upthrown side of up-to-the-coast faults wherever structural closure along the strike is found either from anticlinal nosing or a change in strike of the fault.

A down-to-the-coast fault that does not have an anticline associated with it is not considered a reliable oil barrier. Oil will not necessarily accumulate where beds are truncated against the fault on the downthrown side because the top of a reservoir bed might be dropped down against a lower part of the same bed and allow migrating oil to leak across the fault. A down-to-the-coast fault that has no apparent dip into its downthrown side, however, does not have to be unfavorable. A steep dip right at the fault plane might not be detected by seismograph. Figure 15 is an example of no apparent reverse dip on horizon 2, but on several other horizons a steep dip right at the fault seems probable.

INTERPRETATION TECHNIQUE

The basic principle used for interpretation was that of transferring the data from the records to the sections as accurately and completely as possible and using the section to locate the fault plane. The records were unmixed to insure that reflections would not be artificially extended and plotted across a fault plane. All visible events on the records were picked and tied continuously, if possible, but were used as split dips or as partial reflections if not. Care was taken to stop a reflection at the exact trace at which it no longer conformed to the weathering pattern template for that spread. The reflections were plotted in two ways on sepa-

* In these Figures the vertical and horizontal scales are equal; depths below sea level marked in 1,000 foot intervals; horizontal reference lines are drawn at sea level and at 10,000 ft., (except Figure 17 which is at −13,000 ft.); the shot points are usually 1,000 feet apart; continuous profiling with 100% subsurface coverage is used; reflections are plotted in migrated position using curved ray path, except in Figure 16, which is by depth directly below shot point; reflection grades are shown by: good—solid line, fair—one question mark, and poor—two question marks; horizons correlated across faults are marked by numbers at sides of figures and by hachure lines on the reflections; regional dip is eastward down toward Gulf, and starts or continues to right of all figures except Figures 7, 13, and 16 where right side is north and regional dip is down to the south at the left; approximate angle between seismograph line and strike of fault is shown at top center of figures; all faults are considered as plane surfaces—apparent changes in dip are a result of change in direction of seismograph line; all figures are exact copies of originals plotted at field offices.

rate sections; as depths directly below the shot point, as shown in Figure 16, and migrated with curved ray path, all other examples, as an aid in distinguishing between actual and apparent reflecting horizons. Two reflections have a persistent recognizable character and they are marked as horizons 1 and 2 on the sections. Independent confirmation on the character correlation across many of the faults was made by continuous time ties around their end or by tying to wells drilled on the two sides.

The faults show up in the sections as a right triangle of distorted or absent data. Reflections above the fault plane are normal, but the reflections below the fault plane are few in number, erratic in dip, and fragmentary. The lack of reflections is notable in Figures 1 and 3. Erratic and fragmentary dips are seen in sections 8, 9, 13 and 15. The fault plane is located on the section along the contact between the normal and distorted portion of the successive profiles affected. Where good reflections are shown crossing the fault plane, the reflections may have been picked optimistically, or the fault could be located slightly in error, or the reflections could be derived from a third dimension out of the plane of the section. Nearly all the sections show on the upthrown side of the fault a vertical contact between the last normal profile and the distorted data, appearing as a shadow beneath the fault. Figure 6 is the only section which shows no distortion below the fault plane.

Two types of distortion can cause erroneous interpretation. The first type is illustrated by Figures 1, 4, 5, 7, 9, 10, 12, 13, and 15. As the fault is approached on the upthrown side, the first distorted profiles under the fault have recognizable reflections with a lag of several hundred feet, as much as 100 milliseconds in time, from the same reflections on the adjacent normal profile. The retarded reflections generally dip away from the fault at about 15 degrees. These dips are not interpreted as representing structure but as erratics derived from an unusual travel path as shown in Figure 18. Ray paths start at the shot hole and intersect the fault plane at the critical angle and are refracted downward adjacent to the plane through the higher velocity beds on the upthrown side of the fault. The rays emerge downward again where the beds on the upthrown side have the necessary lithology to have a lower velocity than the adjacent beds on the downthrown side. They are then reflected from the previously recognized interface and their return paths to the surface are identical. The reflections show a time lag and an erratic dip. The time lag would result from the greater length of the refraction path over the direct path.

Several interesting conclusions can be drawn from the travel paths shown in Figure 18. One is that on a given profile all the deep distorted reflections will have an identical moveout and dip across the records. This has been found true and is particularly apparent in Figures 4, 5, 7, 12 and 13. Another is that successive profiles will have identical time intervals between the same retarded deep reflections. This also checks on the records and can be seen in Figures 4, 7 and 12. The energy returning from the direct path is apparently weak and is rarely recorded, although

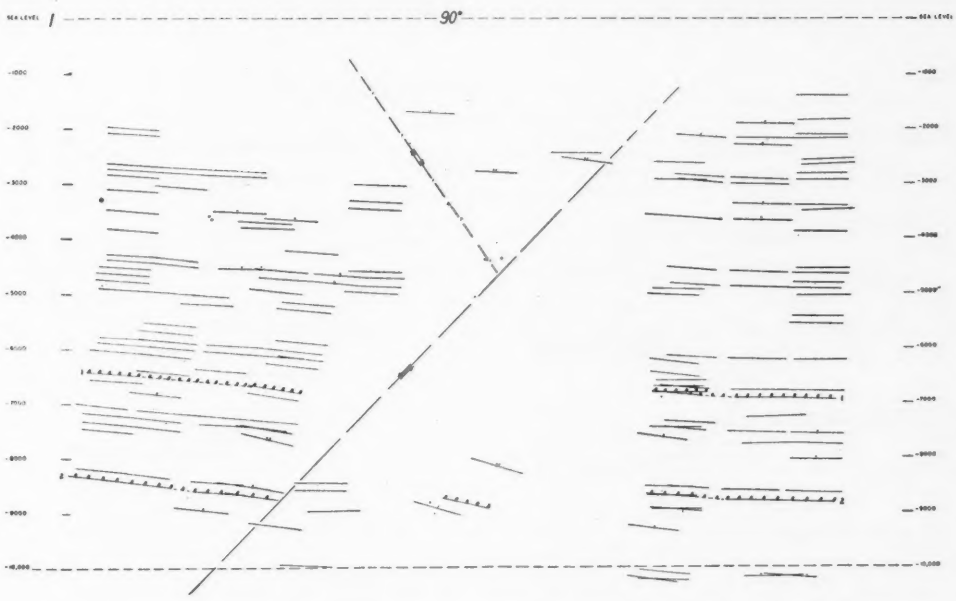

FIG. 1. Up-to-the-coast fault with possible adjustment fault. Shows lack of data below fault plane limited by vertical line of reflections on right and fault plane on left. Reflection from horizon 2 shown in abnormally low position below fault plane and may be result of "drop" type of distortion.

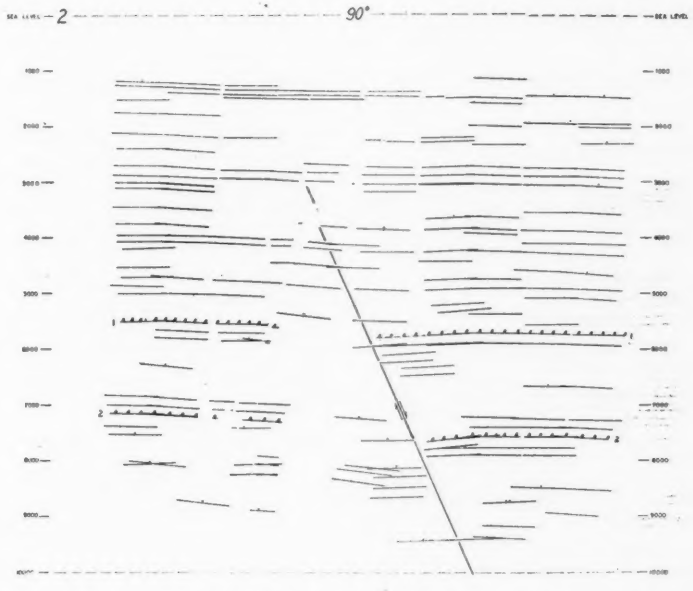

FIG. 2. Fault dying out upward. Shows lack of data below fault plane and anomalous west dip into downthrown side of fault. Note increased interval between horizon 1 and 2 on downthrown side.

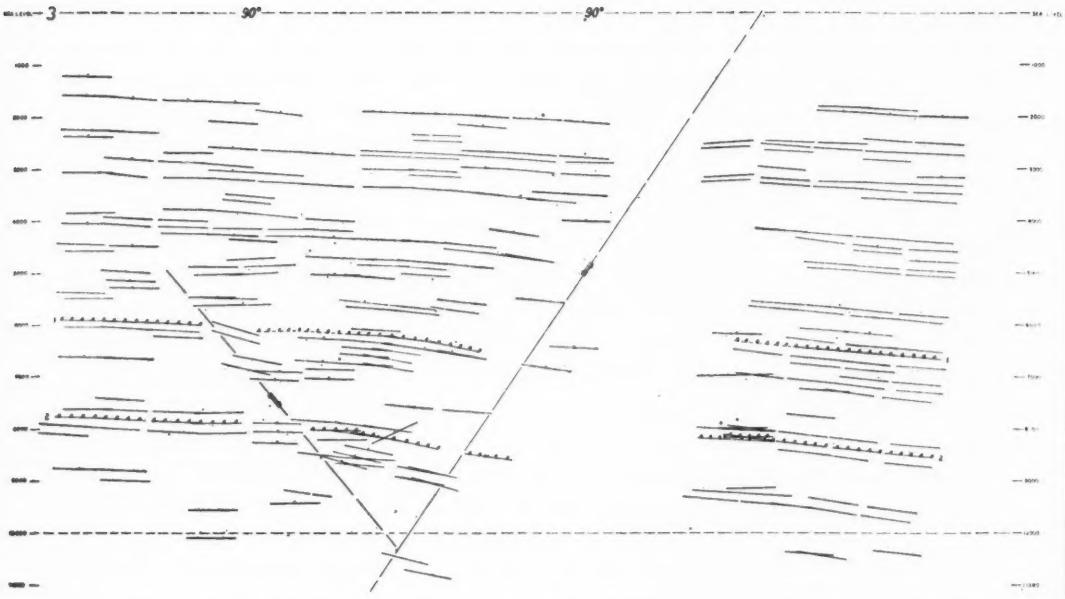

FIG. 3. Up-to-the-coast fault with adjustment fault. Shows lack of data below fault plane and possible "increased dip" type distortion of first profile under upper edge of fault.

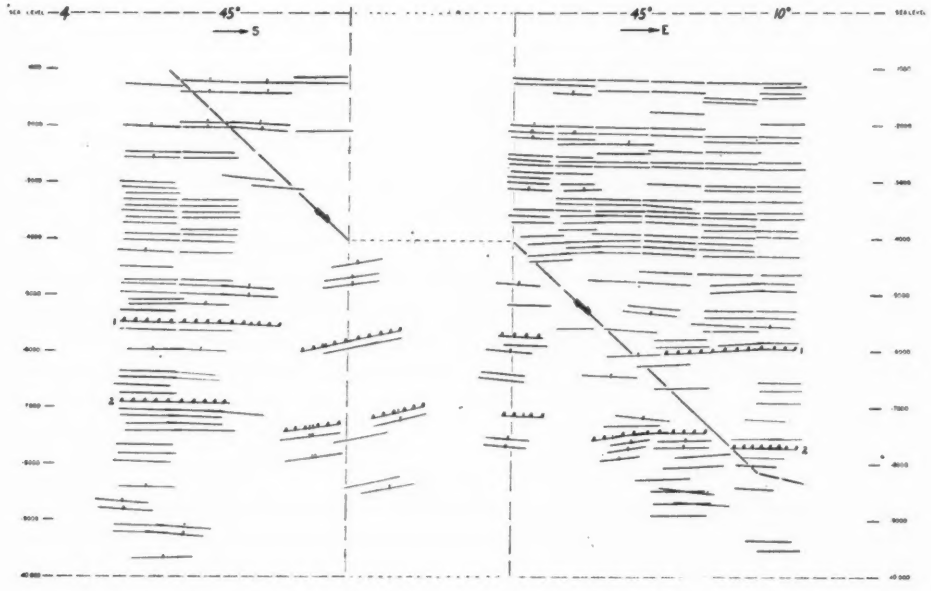

FIG. 4. Fault with reverse dip down into downthrown side of fault and "drop" type of distortion below upper part of fault. Break in section is where seismograph line turned 90° corner. Two additional faults would be mapped on horizon 2 if the reflections were not recognized as distortion.

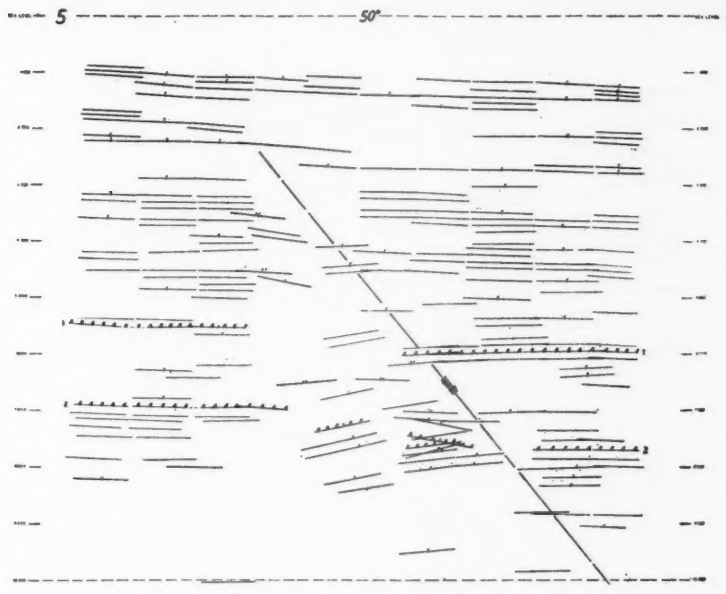

FIG. 5. Fault with slight reversal of dip into downthrown side and "drop" type of distortion below upper part of fault. Two additional faults would be mapped on horizon 2 if the reflections were not recognized as distortion.

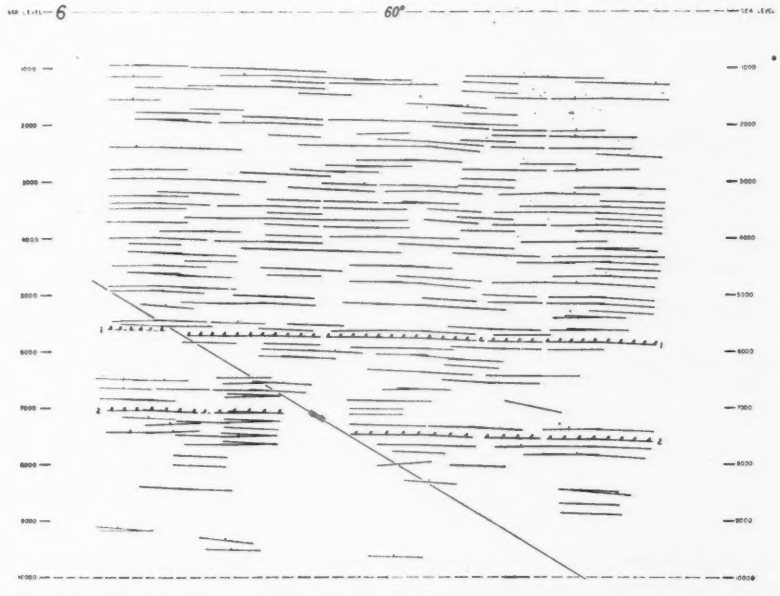

FIG. 6. Fault dying out rapidly upward. Distortion below fault is a minimum.

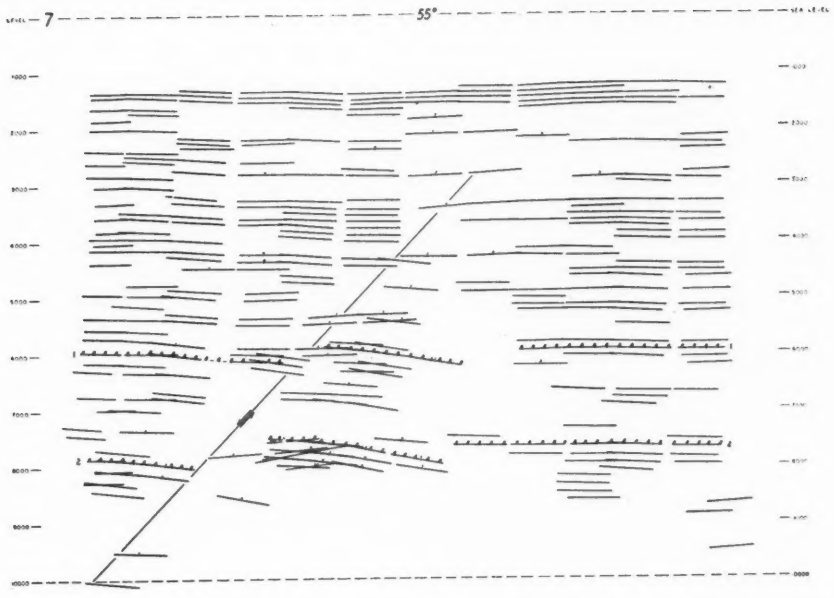

FIG. 7. Down-to-the-south fault showing pronounced "drop" type distortion below upper end of fault. Additional fault and structural trap indicated under main fault if distortion is ignored.

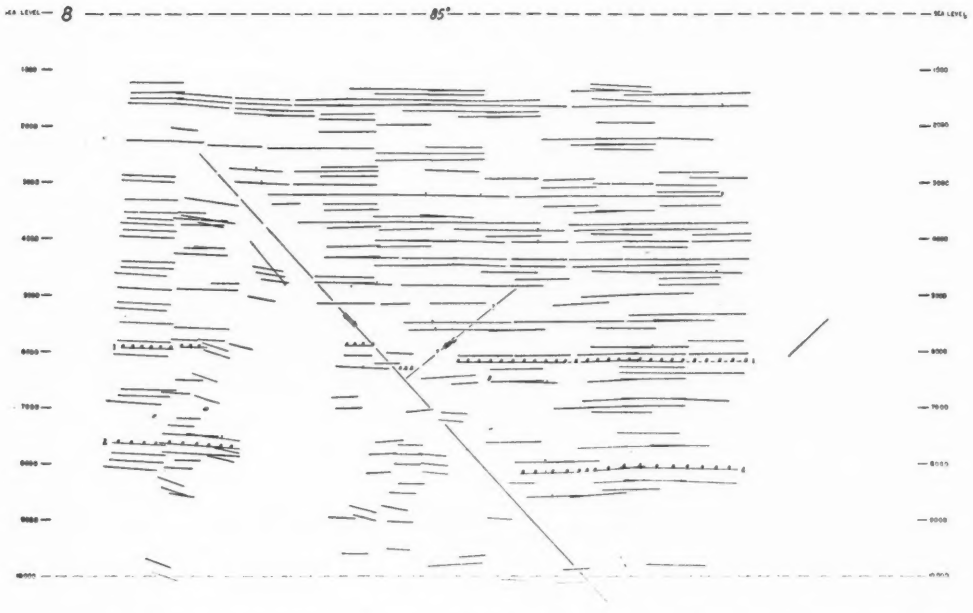

FIG. 8. Fault showing sparse and distorted data below plane. Possible minor adjustment fault. Slight reverse dip into downthrown side. Very steep dip in distortion zone may be reflection from fault surface.

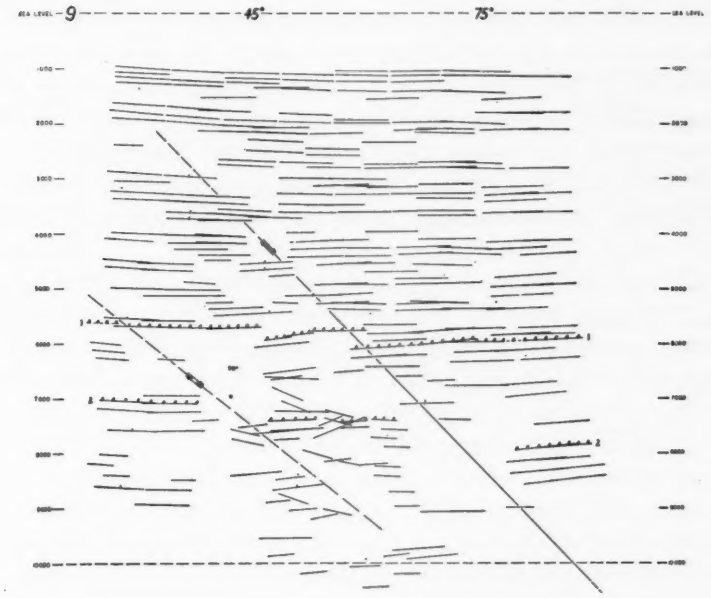

FIG. 9. Main fault on right has reverse dip into downthrown side. "Drop" type distortion below plane apparent on horizon 1 and possible on horizon 2. Fault at left has very little throw on horizon 1. Apparent throw on horizon 2 may be partly "drop" distortion from main fault.

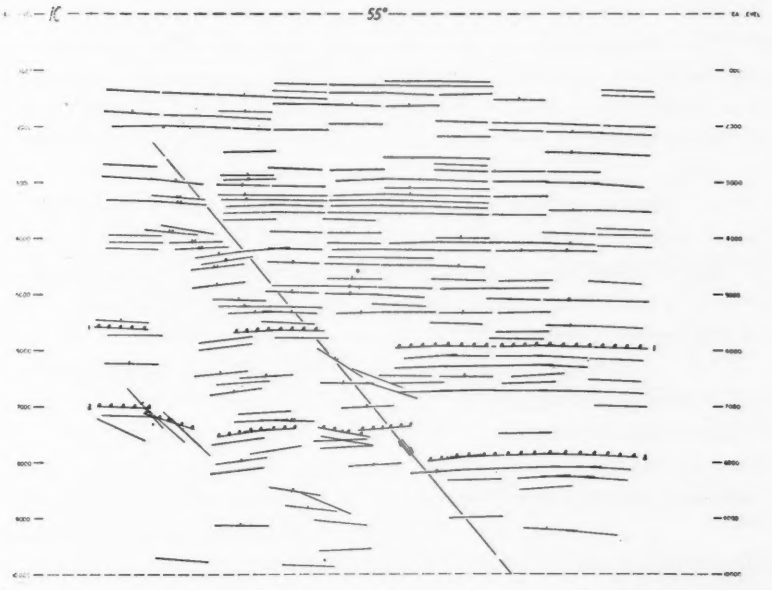

FIG. 10. Fault showing reverse dip into downthrown side and possible "drop" type distortion. Second fault possible under main fault plane. Pronounced increase in interval between horizon 1 and 2 on east side of fault. Dies out upward and does not cut shallow horizon at −1,000 ft.

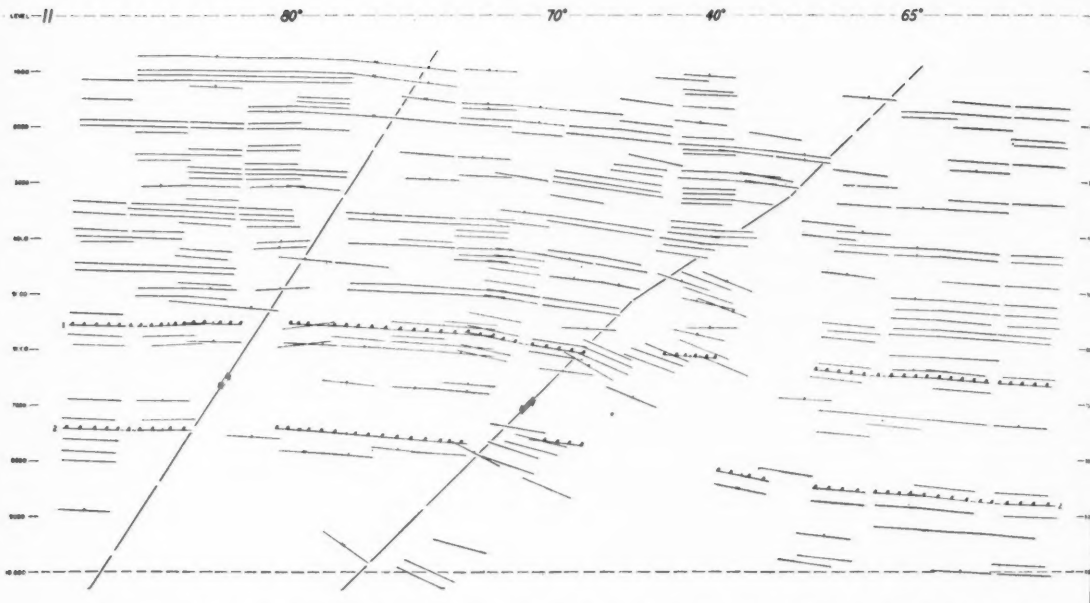

FIG. 11. Two up-to-the-coast faults. Both cut shallow beds. Pronounced distortion below fault on right. Distortion below fault on left may be "increased dip" type (a sag towards fault).

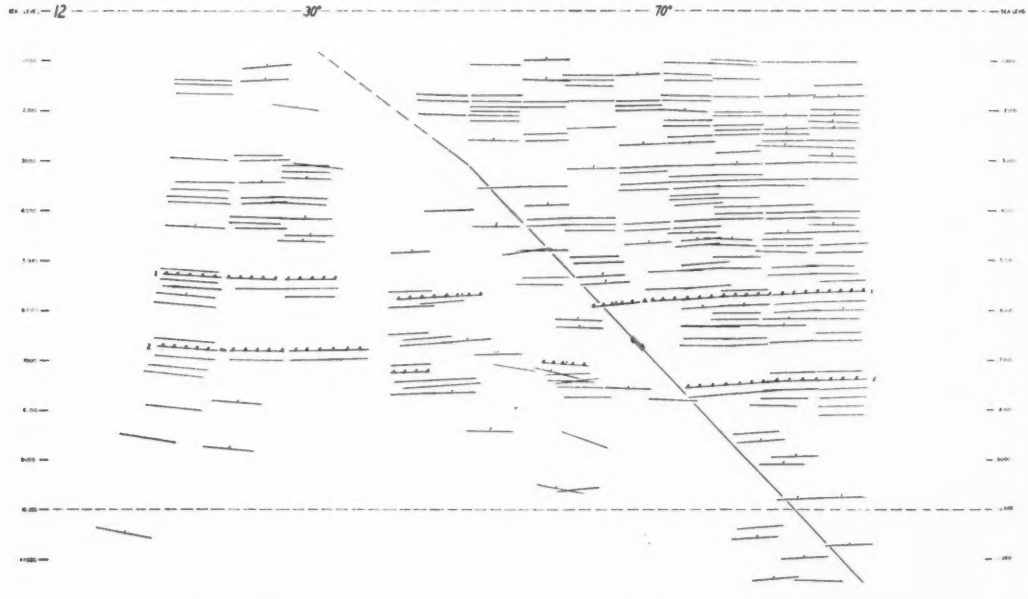

FIG. 12. Fault showing "reverse drag" affect of beds dipping down into downthrown side and bending up towards upthrown side. Pronounced distortion of "drop" type below upper part of fault. Increased interval between horizons 1 and 2 across fault.

at a few places both the normal reflection and the retarded refraction pattern are found on the same record. There duplicated reflections were found on the eight and ninth records from the right side of Figure 4 and the fifth and sixth from the right side of Figure 7. On many sections the thickness of beds between horizons 1 and 2 is much greater on the downthrown side of the fault than on the upthrown. Deposition must have occurred during faulting then, and the nature of the sedimentation right at the fault plane might affect the travel path in an unknown manner.

The steep dip away from the fault plane shown by the retarded reflections can be explained by the same travel path. At the fault plane in Figure 18 the emerging rays on their return paths would act as point sources of energy in the plane of the section and would show dips away from the fault. The greater moveout that such reflections would have can be found on several records. As the adjacent beds across each fault section are different and give unique relationships the nature and amount of lag and distortion varies. The distortion varies also with the angle at which the line crosses the fault, being the greatest at right angles. The dip of the retarded reflections in Figure 12 is unusually low and the normal moveout is not large. The small angle of 30 degrees between the fault and the line makes the apparent dip and moveout a minimum.

The question must be considered whether or not the abrupt drop under the fault plane is another fault. Figure 9 definitely shows two branches of the same fault, and a second fault could fit into a fault pattern in Figure 10. On all other sections a second fault would merely parallel the main one, and would not be part of a reasonable pattern. As even flat simple dips cannot be recorded within the "shadow zone" of distortion, there is even less probability that additional faulting could be found. The fault planes would have to be nearly vertical along the contact between distorted and undistorted data, and a vertical fault below the upper end of a low angle fault is geologically improbable.

The considerable thickening of the beds between horizons 1 and 2 across many of the faults gives an additional clue to faulting. If two faults were present, some of the increase in thickness could be expected to occur across each fault. However, Figures 4, 7, and 12, show the interval between horizons 1 and 2 to be identical on both sides of the distortion drop. All the thickening takes place across the main low angle fault and indicates it as the only one present.

No wells have been drilled on the two sides of the distortion drop to prove that no fault exists, and none probably will be drilled in such an unfavorable location. In practice, rather than leave the space blank, the recognized horizon is contoured as shown on the sections, including additional faults, and the zone is marked as distorted and probably unreliable.

The second type of misleading distortion below the fault plane is illustrated in Figures 16 and 17, and possibly in Figures 3, 4, 5, 11 and 15. Instead of an abrupt drop at the edge of the vertical distortion boundary, the beds appear to dip down at a steeper than normal angle. Figure 16 shows the increased dip to be

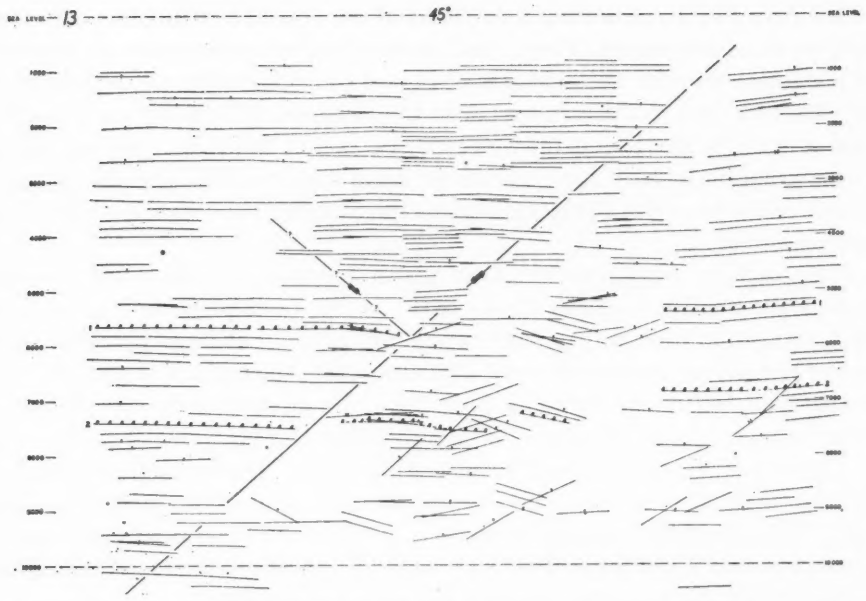

FIG. 13. Down-to-the-south fault. Vertical line of distortion under upper part of fault and "drop" type distortion on horizon 2. Possible adjustment fault. Two additional faults may be interpreted below main fault plane if horizon 2 reflections are considered reliable. Very steep dips may be refraction-reflections or straight reflections from fault surface.

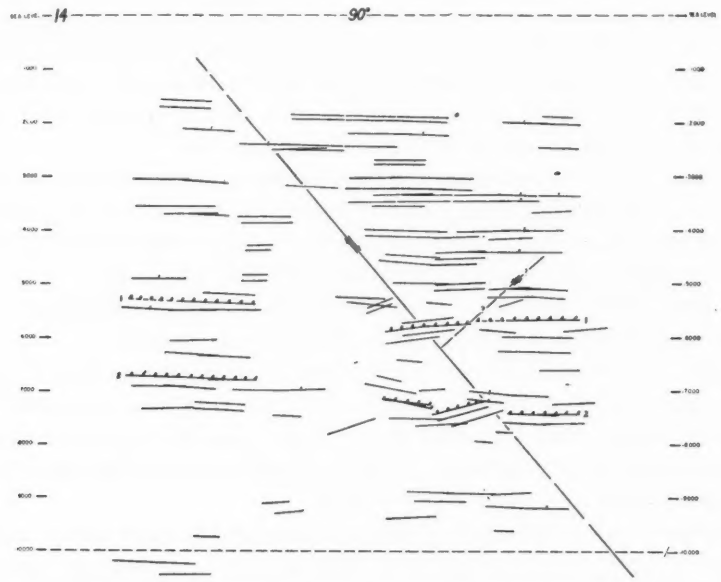

FIG. 14. Fault with vertical distortion break and possible adjustment fault cutting horizon 1.

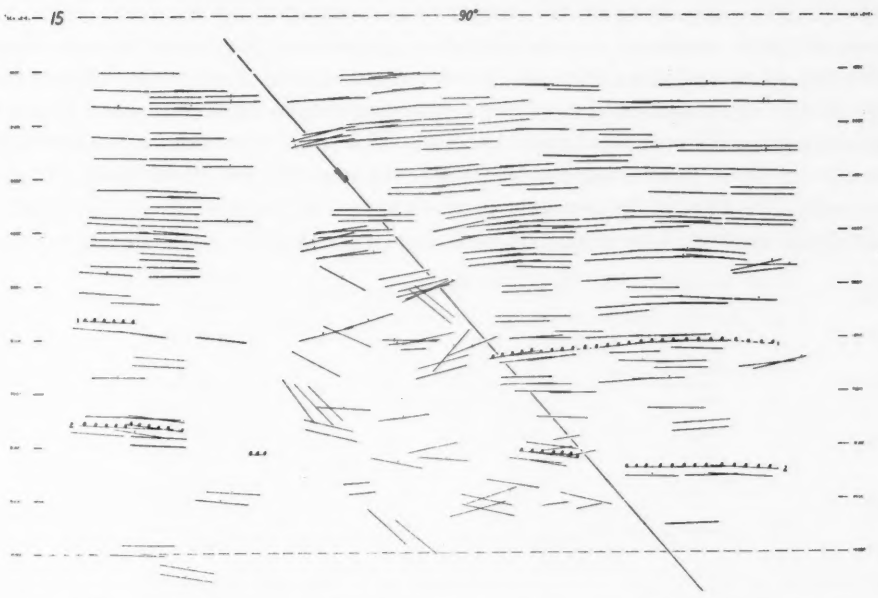

FIG. 15. Pronounced distortion with vertical contact below upper edge of fault. Possible "drop" type distortion. Reflections from fault plane apparent. Steep dip right at fault plane into downthrown side.

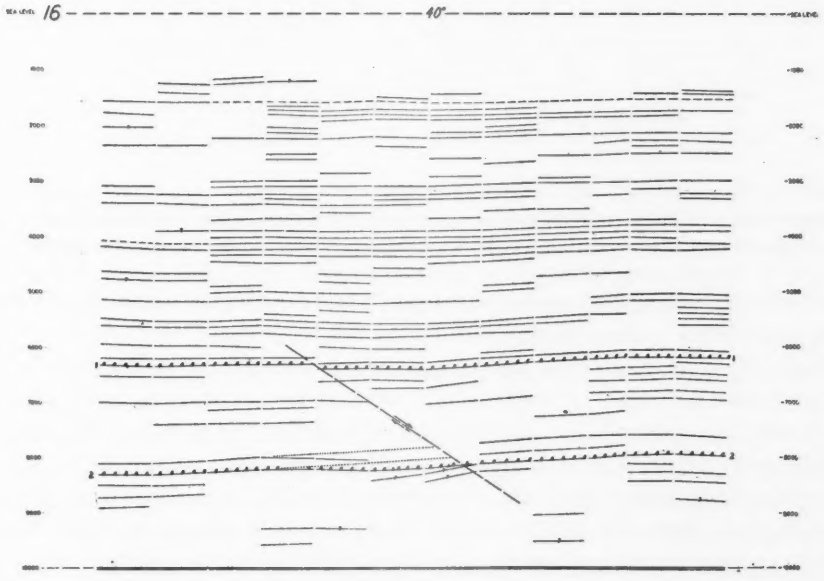

FIG. 16. Down-to-the-north fault. "Increased dip" type of distortion below fault plane makes apparent continuous tie on horizon 2 and hides fault. Dotted line shows expected true position of beds.

just enough to appear to tie the deeper beds aross and hide the fault. Figure 17 shows so much increased dip that horizons 3 and 4 on the upthrown side of the fault appear to be deeper than on the downthrown side. The dotted lines in Figures 16 and 17 are projections of the dip on the upthrown side and are meant to show the probable true position of the beds. The shallower beds on both sections are not significantly affected by the distortion and show the approximate throw of the fault. This type of distortion appears to be associated with faults with throws from 50 to 300 feet. It is explained by a time delay through the gouge zone of the

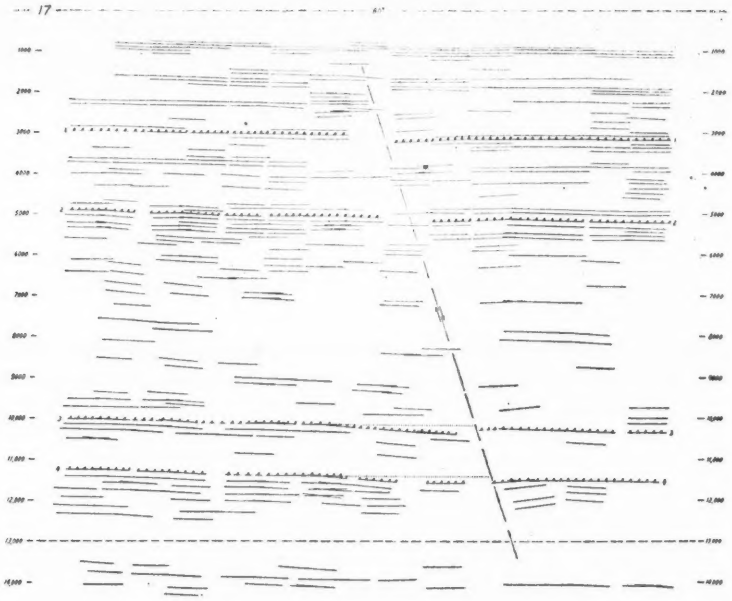

FIG. 17. "Increased dip" type of distortion beginning below upper edge of fault. True direction and magnitude of throw shown on horizon 1 and 2. Distortion makes upthrown side on horizons 3 and 4 appear deeper than downthrown side. Dotted lines show expected true position of beds.

fault or by the refraction pattern shown in Figure 19, which would give a successively greater lag to the reflections under the deeper parts of the fault.

Both types of distortion can cause serious interpretation errors. The first "drop" type can cause the fault to be located at the point of the distortion drop which may be a half mile to a mile and a half from its true position. The true fault displacement might not be so pronounced on the records as the distortion drop and could be missed—especially if the record quality in general were poor, and the reflection character were only fair. An error would almost certainly be made if only a single reflecting horizon were being carried on the records and a cross section showing all the reflection data were not available. Locating two faults instead of one is the most probable error and three faults might be located in Figures 4, 5 and 13. The "increased dip" or "sag" type of distortion could cause the

fault to be missed entirely or the direction of throw could be wrong. The fault in Figure 16 was missed on the original interpretation of horizon 2 and was not found until horizon 1 was mapped later. In Figure 17 a fault with the downthrown side to the west was the preliminary interpretation of horizons 3 and 4 until the shallower horizons were studied. Other seismic lines also have crossed this same fault and confirmed the down-to-the-coast interpretation.

Some unusually steep dips associated with the fault distortion pattern are seen in Figures 3, 8, 10, 13 and 15. Some may be reflections from the fault plane

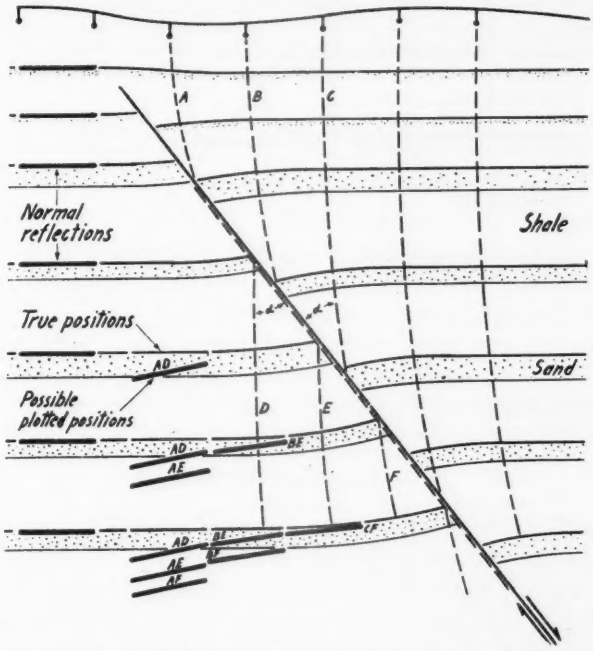

FIG. 18. Shows ray paths *A*, *B*, and *C* of three shot points reaching fault plane at critical angle and refracting downward along higher velocity upthrown side. All emerge downward again along *D*, *E*, or *F* and reflect back from one or more recognizable horizons. The resulting unmigrated plotted split reflections illustrate possible results of "drop" type of distortion. Shale assumed to have higher velocity than sand.

itself or they may be refraction waves reflected from the fault zone as described by Robinson (1945).

The variables at each fault section are too numerous for computing the location of the interfaces from which the distorted reflections are derived. There may be no distortion at all as apparent in Figure 6, or both the "drop" and "sag" types could exist together as suggested in Figures 4, 5 and 15. The structure beneath the fault plane on distorted sections is therefore unknown or highly questionable. Some indication of interface position can be estimated by assuming that the reflections may lag in time and indicate a greater than true depth, but they could not arrive early and indicate too shallow a depth.

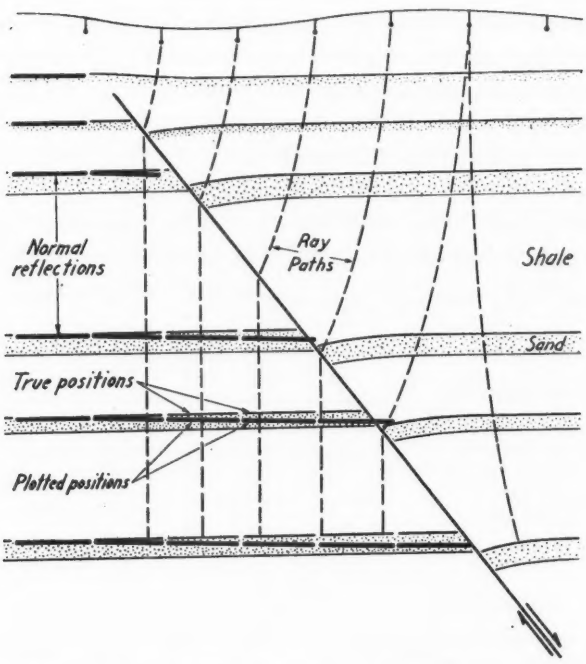

FIG. 19. Shows ray paths refracting across fault plane. Plotted position of reflecting horizon gets deeper towards right and illustrates "increased dip" type of distortion.

CONCLUSION

Mapping faults in Southwest Texas can be simplified if the interpreter is well acquainted with the unusual structural characteristics he may encounter. They are as follows: shallow dip of the normal fault planes, "reverse drag" appearance of dips on each side of the fault, and the rapid dying out of movement both vertically and horizontally. Every bit of data available on the records should be transferred to the cross sections and the interpretation made on the sections. A zone of distorted or fragmentary data may be found in the shadow of the fault plane. Two separate distortion patterns must be recognized if faults are not to be improperly located, missed entirely, or reversed in direction of throw.

ACKNOWLEDGMENTS

The writer wishes to express his appreciation to Magnolia Petroleum Company for permission to publish this paper and to Rex White, Ray Dobyns, Jake Menefee and Paul Nash for their help and consideration in making the paper possible. Dr. Hewitt Dix and Dr. Raymond Peterson are foremost of the many who have contributed to the paper by their ideas, criticism, and encouragement.

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A METHOD OF ELECTRICAL PROFILING*

KENNETH C. CRUMRINE†

ABSTRACT

A method useful in electrical exploration is presented. In electrical profiling using a sensitive low frequency instrument, a considerable variety of information can be obtained at relatively small expense by making a suitable choice of electrode patterns for three measurements at each station along a profile. Apparent resistivities pertaining to relatively large electrode spreads can be computed from shorter spread measurements along a profile, and a variety of potential drop ratios can also be computed. Suitable instrumentation should afford automatic recording of a variety of electrical functions in continuous profiling at or near the surface of the earth, and in bore holes.

In apparent resistivity methods (Heiland, 1940) electric current is passed through the ground between two energizing electrodes and the resultant potential difference between two probe electrodes is measured. The ratio of this potential difference to the energizing current is the mutual resistance of the ground for the particular electrode pattern if direct current or sufficiently low frequency alternating current is used. The mutual resistance multiplied by a geometric factor (Heiland, 1940) determined by the electrode pattern is the apparent resistivity of the ground for the particular electrode pattern.

It has been customary to choose an electrode pattern and to space the four electrodes along a straight line profile. The pattern chosen may then be moved bodily with fixed spacing along profiles traversing an area and an apparent resistivity map can be prepared and interpreted for the depth zone pertaining to the pattern and spacing used. Alternatively, the center of the pattern chosen may remain in a fixed location and the electrode spacing may be increased. Such an expansion of the electrode pattern yields apparent resistivity versus spacing curves ordinarily interpreted for different and increasing depths at the fixed location.

Extended areal coverage is promoted by the profiling procedure using fixed spacing. Knowledge of the electrical section is gained by the expansion technique. Where both methods are used on a survey in order to support a geologic interpretation more adequately, one type of information is often obtained at the expense of the other.

Both areal coverage and knowledge of the electrical section are promoted by the method of profiling which in outline is as follows. Three measurements are made at each station, using three patterns with fixed electrode spacing along profiles. The mutual resistances pertaining to a total of twenty-two electrode patterns thereby become known to the interpreter. Ten of these patterns have total electrode spreads larger than those used in the measurements. The as-

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sociated apparent resistivities in general may all be different because of lateral or vertical variations in the resistivity of the ground. The variety of apparent resistivities and other electrical functions afforded by the method at relatively low cost is conducive to effective geological interpretations of electrical surveys. The method is presented in detail below.

TABLE I. APPARENT RESISTIVITIES KNOWN FROM THREE OBSERVATIONS ALONG A PROFILE

O = Energizing Electrode, X = Probe Electrode, or Vice Versa

e, s, w = Apparent Resistivities; E, S, W = Mutual Resistances

Pattern No.	Electrode or Station Numbers									Station No.*
	$n-3$	$n-2$	$n-1$	n	$n+1$	$n+2$	$n+3$	$n+4$		
							$\leftarrow a \rightarrow$			
1			O	O	X	X			$e = 6\pi a\, E$	$n+\frac{1}{2}$
2			O	X	O	X			$s = 3\pi a\, S$	$n+\frac{1}{2}$
3			O	X	X	O			$w = 2\pi a\, W$	$n+\frac{1}{2}$
4		X	X	O		O			$e_{112} = \frac{24}{5}\pi a\, E_{112}$	n
5		O		O	X	X			$e_{211} = \frac{24}{5}\pi a\, E_{211}$	n
6		O	O		X	X			$e_{121} = 24\pi a\, E_{121}$	n
7		X	O	X		O			$s_{112} = 8\pi a\, S_{112}$	n
8		O		X	O	X			$s_{211} = 8\pi a\, S_{211}$	n
9		O	X		O	X			$s_{121} = \frac{8}{5}\pi a\, S_{121}$	n
10		O	X	X		O			$w_{112} = 3\pi a\, W_{112}$	n
11		O		X	X	O			$w_{211} = 3\pi a\, W_{211}$	n
12		O	X		X	O			$w_{121} = \frac{3}{2}\pi a\, W_{121}$	n
13		O	X	X			O		$w_{113} = \frac{24}{7}\pi a\, W_{113}$	$n+\frac{1}{2}$
14		O			X	X	O		$w_{311} = \frac{24}{7}\pi a\, W_{311}$	$n+\frac{1}{2}$
15		O	X		X		O		$w_{122} = \frac{24}{11}\pi a\, W_{122}$	$n+\frac{1}{2}$
16		O		X		X	O		$w_{221} = \frac{24}{11} W_{221}$	$n+\frac{1}{2}$
17		O	X			X	O		$w_{131} = \frac{4}{3}\pi a\, W_{131}$	$n+\frac{1}{2}$
18		O		X	X		O		$w_{212} = 6\pi a\, W_{212}$	$n+\frac{1}{2}$
19	O		X	X			O		$w_{213} = 8\pi a\, W_{213}$	n
20	O			X	X		O		$w_{312} = 8\pi a\, W_{312}$	n
21	O		X		X		O		$w_{222} = 4\pi a\, W_{222}$	n
22	O			X	X			O	$w_{313} = 12\pi a\, W_{313}$	$n+\frac{1}{2}$

* The station number given in the right hand column for each electrode pattern specifies the location along the profile of the point half way between the outer electrodes in each pattern.

In Table I at the top is diagrammed a short section of an electrical profile including eight electrode locations spaced a distance "a" apart and identified by consecutive integers from $n-3$ to $n+4$ inclusive. Each electrode pattern shown below this profile section consists of two circles designating energizing electrodes, and two crosses denoting probe electrodes. The mutual resistance corresponding to each electrode pattern is referred to the point half way between the two outer electrodes. The location of this point for each pattern is specified by the station number given in the column on the right. It is seen that if the distance between

TABLE II. NINETEEN MUTUAL RESISTANCES EXPRESSED IN TERMS OF THE THREE MUTUAL RESISTANCES E, W, AND E_{121} ASSUMED TO BE OBSERVED ALONG A PROFILE

The Mutual Resistances are Written as Functions of the Station Number, n, along a Profile

$$
\begin{aligned}
S(n+\tfrac{1}{2}) &= W(n+\tfrac{1}{2}) - E(n+\tfrac{1}{2}) \\
E_{112}(n) &= E(n-\tfrac{1}{2}) + E_{121}(n) \\
E_{211}(n) &= E(n+\tfrac{1}{2}) + E_{121}(n) \\
S_{112}(n) &= W(n-\tfrac{1}{2}) - E(n-\tfrac{1}{2}) - E(n+\tfrac{1}{2}) - E_{121}(n) \\
S_{211}(n) &= W(n+\tfrac{1}{2}) - E(n-\tfrac{1}{2}) - E(n+\tfrac{1}{2}) - E_{121}(n) \\
S_{121}(n) &= W(n-\tfrac{1}{2}) + W(n+\tfrac{1}{2}) - E(n-\tfrac{1}{2}) - E(n+\tfrac{1}{2}) - E_{121}(n) \\
W_{112}(n) &= W(n-\tfrac{1}{2}) - E(n+\tfrac{1}{2}) \\
W_{211}(n) &= W(n+\tfrac{1}{2}) - E(n-\tfrac{1}{2}) \\
W_{121}(n) &= W(n-\tfrac{1}{2}) + W(n+\tfrac{1}{2}) - E(n-\tfrac{1}{2}) - E(n+\tfrac{1}{2}) \\
W_{113}(n+\tfrac{1}{2}) &= W(n-\tfrac{1}{2}) - E(n+\tfrac{1}{2}) - E_{121}(n+1) \\
W_{311}(n+\tfrac{1}{2}) &= W(n+3/2) - E(n+\tfrac{1}{2}) - E_{121}(n) \\
W_{122}(n+\tfrac{1}{2}) &= W(n-\tfrac{1}{2}) + W(n+\tfrac{1}{2}) - E(n-\tfrac{1}{2}) - E(n+\tfrac{1}{2}) - E(n+3/2) - E_{121}(n+1) \\
W_{221}(n+\tfrac{1}{2}) &= W(n+\tfrac{1}{2}) + W(n+3/2) - E(n-\tfrac{1}{2}) - E(n+\tfrac{1}{2}) - E(n+3/2) - E_{121}(n) \\
W_{131}(n+\tfrac{1}{2}) &= W(n-\tfrac{1}{2}) + W(n+\tfrac{1}{2}) + W(n+3/2) - E(n-\tfrac{1}{2}) - 2E(n+\tfrac{1}{2}) - E(n+3/2) - E_{121}(n) \\
&\quad - E_{121}(n+1) \\
W_{212}(n+\tfrac{1}{2}) &= W(n+\tfrac{1}{2}) - E(n-\tfrac{1}{2}) - E(n+3/2) \\
W_{213}(n) &= W(n-\tfrac{1}{2}) - E(n-3/2) - E(n+\tfrac{1}{2}) - E_{121}(n+1) \\
W_{312}(n) &= W(n+\tfrac{1}{2}) - E(n+3/2) - E(n-\tfrac{1}{2}) - E_{121}(n-1) \\
W_{222}(n) &= W(n-\tfrac{1}{2}) + W(n+\tfrac{1}{2}) - E(n-3/2) - E(n-\tfrac{1}{2}) - E(n+\tfrac{1}{2}) - E(n+3/2) - E_{121}(n-1) \\
&\quad - E_{121}(n+1) \\
W_{313}(n+\tfrac{1}{2}) &= W(n+\tfrac{1}{2}) - E(n-\tfrac{1}{2}) - E(n+3/2) - E_{121}(n-1) - E_{121}(n+2)
\end{aligned}
$$

the two outer electrodes is an even multiple of "a," the station number is an integer; if the distance is an odd multiple of "a," the station number is an integer plus one-half. Such stations are called whole and half stations respectively.

The mutual resistance corresponding to each electrode pattern in Table I is denoted by a capital letter, the sequence of subscripts for the extended patterns giving the successive distances between adjacent electrodes from left to right in multiples of "a." The letter E is used in association with patterns for which both of the energizing electrodes are located to the left or right of both probe electrodes. The letter S is used for patterns in which energizing and probe electrodes are staggered. The letter W is used in connection with patterns for which both probe electrodes are located between the energizing electrodes. The apparent resistivities are denoted by the corresponding small letters, e, s, and w, using the same subscripts. The formula for the apparent resistivity in terms of the mutual resistance associated with each pattern is included in Table I.

Frequently four consecutive electrodes have been connected by means of field cables to a suitable instrument using the type pattern (No. 3 in Table I) de-

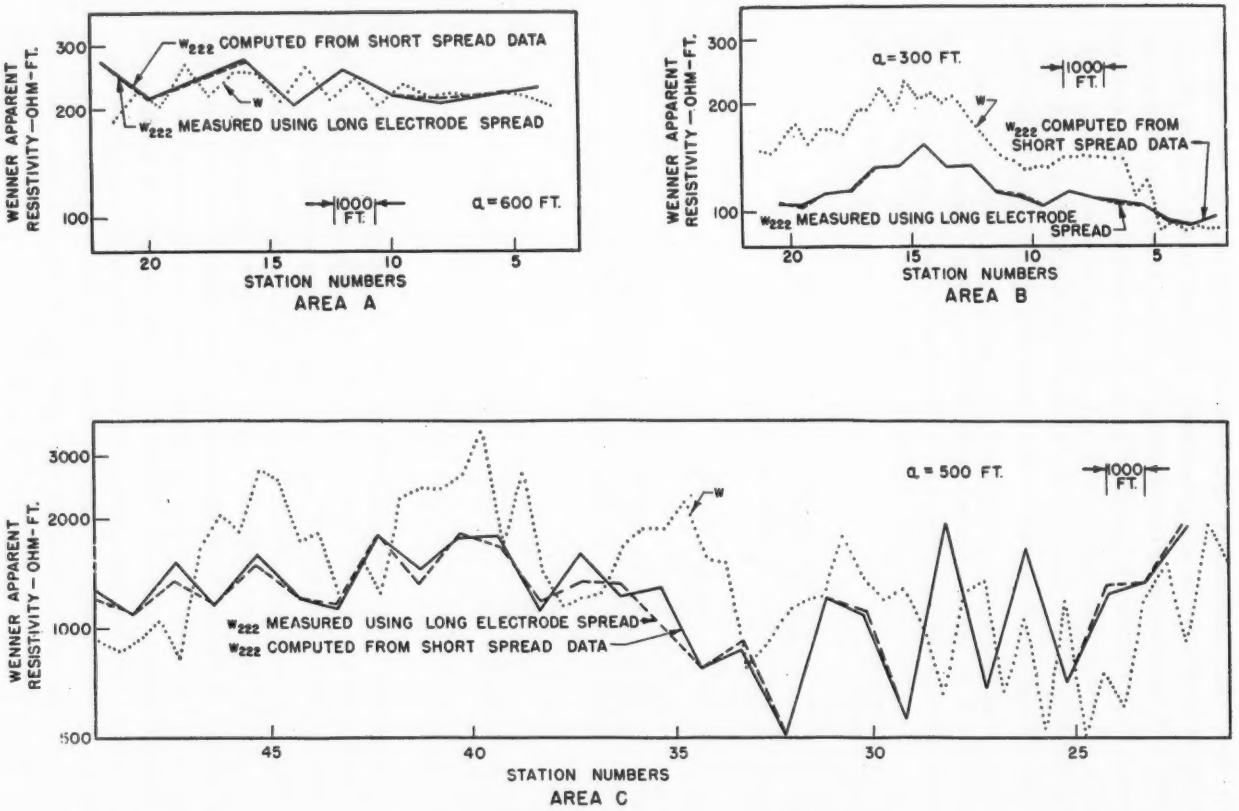

FIG. 1. Experimental verification of the formula for W_{222} as given in Table II. Three Wenner apparent resistivity profiles from widely separated areas are shown, the plotted values being connected by straight line segments. The values of the Wenner apparent resistivity, w_{222}, from measurements using electrode pattern No. 21 in Table I are indicated by the dashed curves. The values of w_{222} computed from measurements using patterns 1, 3, and 6 in Table I are shown by the solid curves. The differences between the solid and dashed curves are within the limits of error of the field instrument. The values of w are shown by the dotted curves for comparison with the other results for the doubled electrode spread. The values of "a" are for "a" as defined in Table I.

scribed by Wenner (1916), and W has been determined at all half-stations along a profile. Then the Wenner apparent resistivity, w, is available for interpretation. Sometimes profiles have been run again using increased electrode separation (for example, pattern No. 21 in Table I) in order to get additional information about the ground at greater depth.

If five consecutive electrodes are connected, however, additional information at different depths can be obtained without the use of such large spreads of field cable at each station. If, for example, the mutual resistances E and W (using patterns 1 and 3) are determined at all half-stations along a profile, and E_{121} (using pattern 6) is determined at all whole stations, then all of the apparent resistivities of Table I along the profile become known to the interpreter. The remaining nineteen mutual resistances of Table I are expressed in terms of the three mutual resistances W, E, and E_{121} in Table II. Here each mutual resistance is written as a function of the station number n along a profile.

The relations in Table II hold for a linear ground, and any conditions of inhomogeneity and anisotropy. The equations can be checked by substituting for the several mutual resistances the theoretical point potentials of which they are composed. For example, let the bottom equation in Table II be considered. For typographical simplicity, consider any eight electrodes numbered from 1 to 8 inclusive and let $n=4$. The equation in question can then be written as follows:

$$W_{313}(4\tfrac{1}{2}) = W(4\tfrac{1}{2}) - E(3\tfrac{1}{2}) - E(5\tfrac{1}{2}) - E_{121}(3) - E_{121}(6).$$

Let the potential at any point "k" due to unit current source at any point "i" be denoted by b_{ik} (or alternatively by b_{ki} because probe and energizing electrodes can be interchanged). In terms of these theoretical quantities, the measurable quantity on the left side of the above equation is

$$W_{313}(4\tfrac{1}{2}) = b_{14} - b_{15} - b_{48} + b_{58}$$

and the right side of the equation is

$$(b_{34} - b_{35} - b_{46} + b_{56}) - (b_{34} - b_{24} - b_{35} + b_{25}) - (b_{56} - b_{46} - b_{57} + b_{47})$$
$$- (b_{24} - b_{14} - b_{25} + b_{15}) - (b_{57} - b_{47} - b_{58} + b_{48}) = b_{14} - b_{15} - b_{48} + b_{58}.$$

It is thus seen that the equation in question is theoretically verified.

Experimental verification of the formulas in Table II has been obtained using field data from widely separated areas. An example is given in Figure 1, where three Wenner apparent resistivities are shown for profiles from three areas, the plotted values being connected by straight line segments. The values of the Wenner apparent resistivity, w_{222}, from measurements using electrode pattern No. 21 in Table I are shown by the dashed curves. The values of w_{222} computed from measurements using patterns 1, 3, and 6 in Table I are shown by the solid curves. The differences between the solid and dashed curves are within the limits of error of the field instrument. The values of the Wenner apparent resistivity, w, from measurements using pattern No. 3 of Table I are shown by the dotted curves

solid and dashed curves are within the limits of error of the field instrument. The values of "a" are for "a" as defined in Table I. comparison with the other results for the doubled electrode spread.

for comparison with the results for the doubled electrode spread. The values of "a" given in Figure 1 are for "a" as defined in Table I.

A variety of ratio functions can be constructed from the apparent resistivities of Table I. For example, all potential drop ratios which are observable with ratio-measuring apparatus using five consecutive electrodes along the profile can be computed. As another example, the Lee partitioning function (Lee and Hemberger, 1946) can be constructed from w_{312} and w_{213} (patterns 19 and 20 in Table I). Such ratios of apparent resistivities corresponding to electrode patterns which are mirror images can differ from unity because of lateral variation in the resistivity of the ground.

The relations given in Table II are valid also in connection with electric well logging. In such an application, and in continuous horizontal profiling at or near the surface of the earth, suitable instrumentation can be devised to record automatically a variety of electrical functions such as those mentioned.

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GEOPHYSICAL RADIO FIELD INTENSITY MEASUREMENTS*

RADIO FACILITIES COMMITTEE†

Part 11 of the Federal Communications Commission's Rules and Regulations —Rules Governing Industrial Radio Services, effective July 1, 1949, now governs the use of radio in connection with geophysical prospecting. Paragraph 11.57e specifies that an application for authority to operate on one of the frequencies in the range 1.6–6.0 mc must be fully justified and accompanied by a showing that

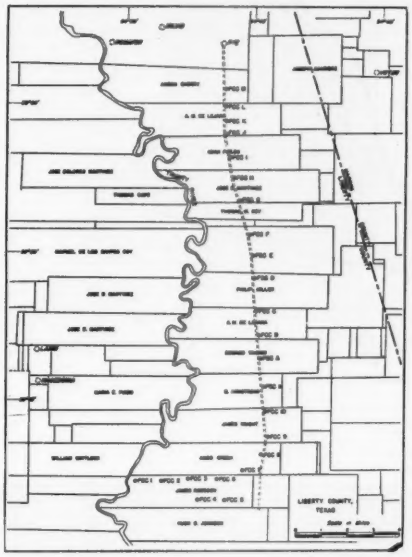

FIG. 1. Field intensity survey line, Liberty County, Texas.

it is impossible to use a higher order of frequencies for accomplishment of the same purposes. This applies to the traditional medium frequencies 1602 to 1700 kc used in geophysical prospecting communications.

In order to determine whether it would be possible under adverse conditions to do geophysical prospecting without the use of these medium frequencies, a series of field intensity measurements were made in Liberty County, Texas on July 22, 1949 and October 21, 1949. These tests were made after discussion with the Radio Facilities Committee of the Society of Exploration Geophysicists and the Sub-committee on Geophysical Use of Radio of the Central Committee on Radio Facilities of the American Petroleum Institute. Observers from the FCC were present when the tests were performed and a report containing the data was submitted to the FCC upon the completion of the tests.

A line, shown on Figure 1, located in the heavily wooded Trinity River Valley

* Report of the Committee on Radio Facilities of the Society of Exploration Geophysicists.

† The members of the committee are Bart W. Sorge, John P. Woods, V. Robert Kerr, Daniel Silverman, Richard Brewer, W. M. Rust, Jr. (Vice-Chairman), and R. D. Wyckoff (Chairman).

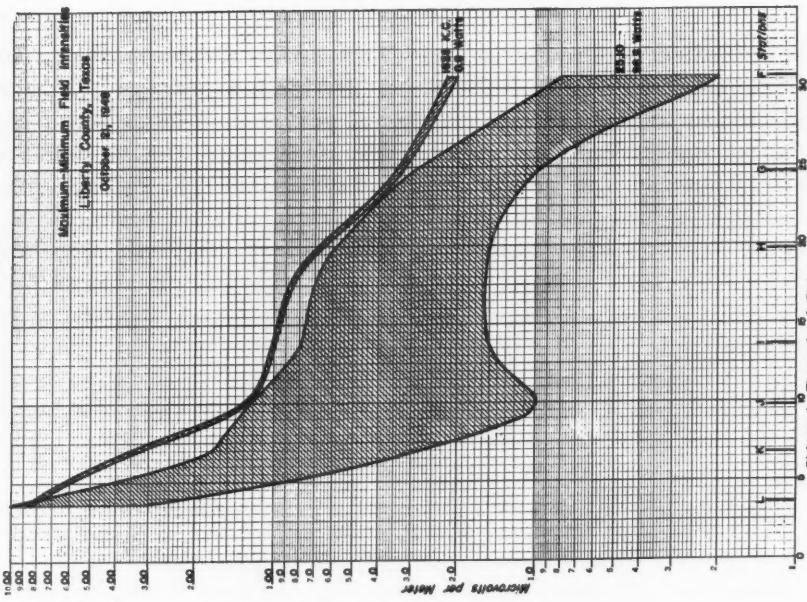

FIG. 3. Maximum-minimum field intensities.

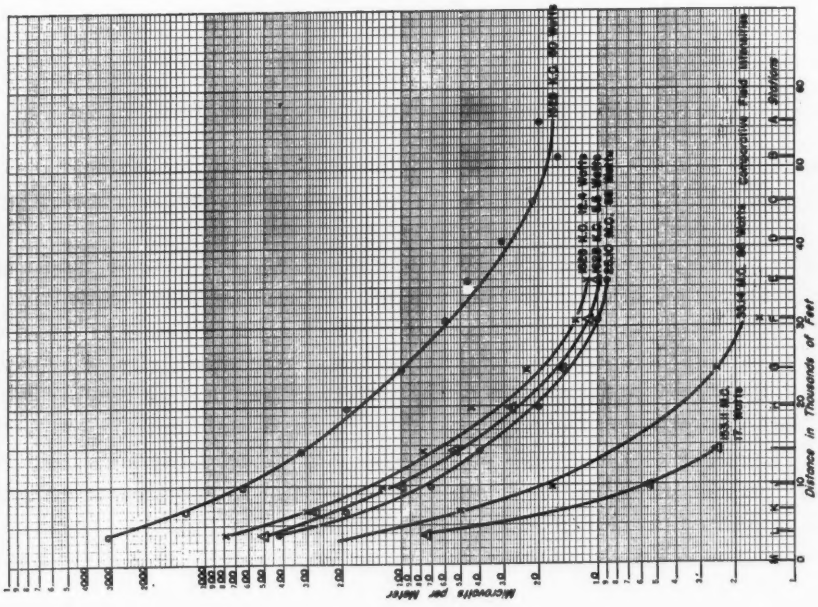

FIG. 2. Comparative field intensities.

was carefully surveyed. In a test conducted on July 22, 1949, six radio transmitters were located at Station M. These included three transmitters on 1628 kc; one with 60 watts input power to the final radio frequency stage and weighing 55 lbs; one with 12.4 watts input weighing 35 lbs; and one with 5.46 watts input; one transmitter on 25.10 mc with 89.25 watts input weighing 76 lbs; one transmitter on 35.14 mc with 86.4 watts input weighing 76 lbs; and one transmitter on 153.11 mc with 17.05 watts input weighing 81 lbs. Field strength measure-

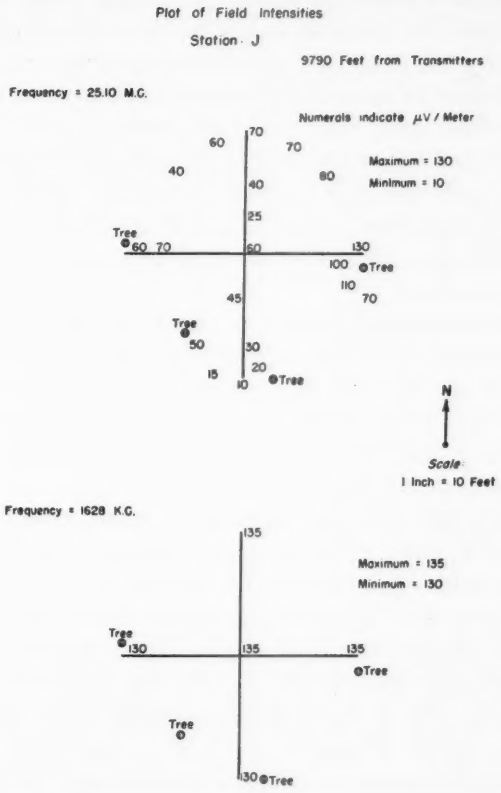

FIG. 4. Variation of field intensities near a point.

ments were made at Stations A, B, C, D, E, F, G, H, I, J, K and L. The results are shown graphically in Figure 2. The values shown represent the average of a number of readings taken at several points over a small area of each of the stations A through L. The actual values varied greatly from point to point at each station, particularly on the frequencies 25.10 mc and higher.

The tests made on October 21, 1949 were restricted to two transmitters, one on 1628 kc with 8.8 watts input weighing 35 lbs, and one on 25.10 mc with 96.9 watts input weighing 76 lbs. Figure 3 shows the resulting data. Two curves are presented for each of the transmitters showing the maximum and minimum field

intensity observed at points at each of the stations F through L. Figure 4 shows a plot of the field intensities for the two transmitters at a number of points at Station J.

The conclusion to be drawn from these data is obvious. In heavily wooded areas, the field intensity at 25 mc is very inconsistent and the attenuation is much greater than at the medium frequencies. Since the geophysical operator must, on occasion, place his radio and seismic instruments at a point arbitrarily selected, he may well have to use the minimum signal intensity level. Indeed, even if he were free to select the position of his station, there would be no practical means for determining the point of optimum signal intensity. This, together with the higher attenuation of 25 mc as compared with the medium frequencies, means that in heavily wooded areas where it is necessary to pack the equipment by means of manpower and where the weight problem is so important, it would be prohibitive to transport the high wattage equipment necessary on 25 mc plus the heavy primary power source necessary for the operation of such equipment. The problem is much more serious on the higher frequencies, such as 35 and 153 mc, as illustrated by Figure 2.

The length of lines involved and the nature of the terrain are typical of conditions which may be met in seismic prospecting. These data establish the impossibility of using a higher order of frequency, among those allocated to the Petroleum Radio Service, than 1602 to 1700 kc for the accomplishment of the same purposes. These data have been submitted to the FCC and may be used by any geophysical applicant by reference.

The companies whose personnel participated in these field tests are: Atlantic Refining Company, Humble Oil & Refining Company, Independent Exploration Company, Magnolia Petroleum Company, Rogers-Ray Inc., Shell Oil Company, Sun Oil Company and The Texas Company. Some of the field intensity measuring equipment was supplied by the West Production Company. Mr. J. H. Wofford, commercial consultant, Mr. R. E. Wack, field engineer of the Federal Telephone and Radio Company, Mr. R. E. Franklin, engineer of the Benjamin Dist. Company, and Messrs. H. F. Weinzel and E. P. Hundurff of the radio stations KLEE and KLEE-TV participated. The observers from FCC were Messrs. J. H. McKinney, L. L. McCabe and G. K. Ashenden.

ANNUAL SURVEY OF GEOPHYSICAL EDUCATION 1949–1950*

JAMES B. MACELWANE, S.J.†

A brief questionnaire was circulated to all those institutions of higher learning who had signified their interest in any form of geophysical education by their replies to the more elaborate enquiry sent to all institutions last year. The positive answers received are best shown by means of the following tabulations. Comparison with the results of the previous year's survey indicates a steady growth in all phases of geophysical education but especially in the field of geophysical exploration.

School	Department of Geophysics	Students 1949–1950		Degrees in Geophysics July 1948 to June 1949			
		Under-Graduates	Graduates	Bachelor	Master	Doctor	Other
Univ. of British Columbia		71		2			
Univ. of California, L. A.		118	71	50	10	10	
Univ. of California, Berkeley		20	7	10			
California Inst. of Tech.	Yes		15		3	2	1
Univ. of Chicago		11	50		29	5	
Colorado School of Mines	Yes	137	15		1		22
Columbia Univ.			18		2	3	
Univ. of Denver		3					
Fordham Univ.		8	2		1		
Harvard Univ.			10				
Johns Hopkins Univ.						1	
Iowa State College	Section	7	4	3	1		
Lehigh Univ.	Option	6	2				
Massachusetts Inst. of Tech.	Meteor.	44	39	6	12	6	
Michigan State College of Mining & Technology			1				
Univ. of North Carolina			1				
Univ. of Oklahoma					2		
Pennsylvania State College	Yes—2 Gph. & Met.	55	17	9	4		
Rensselaer Poly. Inst.		34	3				
St. Louis Univ.	Yes	118	20	48	3		
Univ. of Toronto	Laboratory	20	24	21	6	1	
Univ. of Tulsa		44		8			
University of Utah	Yes			1	1		
Washington Univ.	Section	4	2	2			

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* Report of the Standing Committee on Geophysical Education, Society of Exploration Geophysicists. The members of this committee are: D. C. Skeels, M. King Hubbert, C. A. Heiland, Beno Gutenberg, Perry Byerly and Rev. J. B. Macelwane, chairman. Presented at the Annual Meeting of the Society at Chicago, April, 1950.

† Dean of the Institute of Technology and Director of the Department of Geophysics, Saint Louis University, Saint Louis, Missouri.

Geophysical Exploration

School	Inclusive all Meth-	Theory	Seismic	Gravitational	Magnetic	Electrical	Radioactive	Other
Univ. of Alaska	3-E							
Univ. of Alberta	2-E							
Univ. of British Columbia		½-G	1-E	1–E	1-E	1-E		
			½-G	½-G	½-G			
Univ. of California, L. A.		1-E	1-E	1-E	1-E	1-E		
		1-A	1-A	1-A	1-A	1-A		
		1-G	1-G	1-G	1-G	1-G		
Univ. of California, Berkeley	1-A		1½-A					
California Inst. of Tech.		1-A	1-G	1-G	1-G	2-G		1-A
Univ. of Colorado	2-E							
Colorado School of Mines		3-A	1-A	1-A	1-A	1-A		3-A
		2-G	1-G	1-G	1-G			1-G
Columbia Univ.		1-G						
Univ. of Denver			1-E					
Franklin & Marshall College	1-E							
Harvard Univ.			1-A					
Univ. of Houston	3-E							
Univ. of Idaho	1-E							
Univ. of Illinois	1-E							
Iowa State College	1-E							1-A
								1-G
Univ. of Kansas		1-E						
Louisiana State College	2-E					1-A		
Michigan State College	1½-E							
Michigan College of Mining and Technology		1-G	1-A	½-A	½-A	1-A		
Univ. of Montreal	1-E							
Univ. of Oklahoma	2-A							
Oregon State College	1-E							
Pennsylvania State College	1-E		1-E					1-A
	1-A							
Univ. of Pittsburgh	1-E							
Univ. of Puerto Rico						1-E		
Queen's Univ.	1-E							
St. Louis Univ.		2-A	1-A	1-A	1-A	1-A		
Texas College of Arts & Industries	1-A		2-G					
Texas Christian Univ.	1-E							
Univ. of Toronto		2-A	½+1½-E	½+1½-E	½+1½-E	½+1½-E		
			1½-A	1½-A	1½-A	1½-A		
			1-G	2-G			1-G	
Univ. of Tulsa			1-A	1-A	1-A			
Univ. of Utah			1-A	1-A		1-A		2-A
Xavier Univ.			1-A			1-E		
Washington Univ.	1-E							
	1-A							
	1-G							

School	General Geophysics	Geophysical Engineering	Earthquake Seismology	Meteorology	Oceanography	Other
Univ. of Alaska						3-E
Univ. of Alberta				1-E		
Univ. of British Columbia					1-G	
Univ. of California, L. A.	1-A		1-E	1-E	1-E	
	3-G		1-A	4-A	4-A	
			1-G	4-G	4-G	
Univ. of California, Berkeley	2-A		½-A			
	1-G		4-G			
California Inst. of Tech.	1-A		1-A	½-A	½-A	
	1-G		3-G			
Univ. of Chicago				1-E	1-E	
				15-A	1-A	
				14-G		
Colgate Univ.				1-E		
Univ. of Colorado				1-E		
Colorado School of Mines		1-E				
Columbia Univ.	3-G			1-G	1-G	
Univ. of Connecticut				1-E		
Cornell Univ.					1-E	
Univ. of Denver	1-E					
Drake Univ.				1-E		
East Tennessee State College				1-E		
Fordham Univ.			2-A	1-A		
Univ. of Georgia				1-E		
				1-A		
Georgia Institute of Tech.	1½-A			1½-E		
Harvard Univ.	1-E		1-E	1-G	1-G	
	1-G					
Univ. of Houston					1-E	
Univ. of Illinois				1-E		
Illinois Inst. of Technology				1-E		
Iowa State College	1-E			2-E		
				3-A		
				2-G		
Lehigh Univ.		2-E				
Univ. of Maryland				1-E		
Massachusetts Inst. of Tech.	1-E			7-E	1-E	
				8-A		
				11-G		
Mundelein College				1-E		
Univ. of New Hampshire				1-E		
New Mexico A & M				1-E		
Univ. of New Mexico				2-E		
				2-A		
New York Univ.				8-E	5-G	
				12-G		
Univ. of North Carolina	2-A					
Northwestern Univ.				3-A		
Ohio Univ.				1-E		
				1-A		
Ohio Wesleyan Univ.	1-E			1-E		
Oklahoma A & M	1-E					
Univ. of Oklahoma				2-E		
Oregon State College	1-G		1-G	1-E		
				2-A		
Univ. of Oregon				1-E		
Pennsylvania State College				3-E		
				19-A		
				10-G		

School	General Geophysics	Geophysical Engineering	Earthquake Seismology	Meteorology	Oceanography	Other
Univ. of Puerto Rico	1-E			1-E		
Rensselaer Poly. Tech.	2-E					
Rutgers Univ.	2-E			2-E		
				4-A		
				4-G		
St. Louis Univ.	4-A	1-A	4-A	3-E		
		1-G	2-G	12-A		
				2-G		
Univ. of San Francisco			1-E			
San Jose State College	1-E			1-E	1-E	
				3-A		
Univ. of Saskatchewan				2-E		
Univ. of South Dakota				1-E		
Univ. of Tennessee				1-E		
Univ. of Toledo				1-E		
Univ. of Toronto	2-E		1-G			
	2-A					
	3-G					
Univ. of Tulsa	1-E					
Xavier Univ.	1-A					
Washburn Municipal Univ.				1-E		
Washington University		1-E				
		1-A				
		1-G				
Wayne Univ.				1-E		
				1-A		
Wellesley College				1-E		

E—Elementary.
A—Advanced.
G—Graduate.

DISCUSSIONS AND COMMUNICATIONS

CURRICULUM IN APPLIED GEOPHYSICS
COLLEGE OF MINES AND MINERAL INDUSTRIES
UNIVERSITY OF UTAH, SALT LAKE CITY*

A Department of Geophysics was organized at the University of Utah in September, 1947 under the direction of Professors C. E. Jacob and H. V. W. Donohoo. The course of instruction is based on the philosophy that geophysicists or geologists working in industry require sound training in basic sciences and mathematics, as well as orientation courses in the applied fields. It was further considered that, in general, the physicists' treatment of such subjects as mechanics, electricity, and magnetism, and electronics is more useful to the geophysicist than is the engineering approach. With these ideas in mind, the following curriculum has been evolved. The course is a full one, making it necessary to put such valuable studies as physical chemistry, thermodynamics, geomorphology, and others on the elective list. A laboratory course in well logging methods is offered as an elective, as are several courses in pure geophysics—geodesy, seismology, geomagnetics, oceanography, etc.

The department also offers instruction in ground-water hydrology and, in conjunction with the Geological Engineering Department, grants a B.S. degree in ground water.

No degrees were granted by the department in 1948, but in 1949 a Bachelor's degree and a Master's degree were awarded. Three men are eligible for the Bachelor's degree in 1950, and ten men are ready for the senior class of 1951. The campus now has nine student members of the S.E.G.

MINES AND MINERAL INDUSTRIES
BACHELOR OF SCIENCE IN APPLIED GEOPHYSICS

Sophomore Year

	A	*W*	*S*
Civil Engineering 40 Elementary Surveying	2	0	0
Civil Engineering 3 Descriptive Geometry	0	0	3
Geology 11, 12, 106 Physical, Historical, Structural	4	4	4
Mathematics 21, 22, 23 Calculus	4	4	4
Mineralogy 4, 5 Rock and Ore Minerals	3	3	0
Mineralogy 109 Petrology	0	3	0
Mining Engineering 129 Mine Surveying	0	0	2
Physics 21, 22, 23 College Physics	4	4	4
Physics 24, 25, 26 Laboratory	1	1	1
	18	19	18

Junior Year

Geology 153, 154, 155 Economic Geology	3	3	3
Geology 185 Sedimentation	4	0	0
Geophysics 111, 112 Methods of Prospecting	3	3	0
Geophysics 120 Magnetic Methods	0	0	4
Mathematics 141 Ordinary Differential Equations	4	0	0
Mathematics 143 Operational Calculus	0	4	0
Mathematics 145 Intermediate Differential Equations	0	0	4
Mining Eng. 111, 112, 113 First Aid, Rescue, Hygiene	1	1	1
Physics 151, 152, 153 Electricity and Magnetism	3	3	3
Physics 154, 155, 156 Laboratory	1	1	1
Approved Technical Electives	0	3	3
	19	18	19

* This material was inadvertently omitted from the published report of the Standing Committee on Geophysical Education which appeared in the April 1950 issue.

Summer

Geology 120 Field Geology (4 weeks)	6 credits
Geology 130 Plane Table Mapping (3 weeks)	5 credits

Senior Year

Geology 176, 164 Stratigraphy, Petroleum Geology	5	0	3
Geology 166 Interpretation of Aerial Photographs and Geologic Maps	0	4	0
Geophysics 121, 122 Gravimetric, Seismic Methods	0	4	4
Geophysics 123 Electrical Methods	4	0	0
Geophysics 115 Seminar	0	1	1
Physics 111, 112, 113 Analytical Mechanics	3	3	3
Physics 171, 172, 173 Electron Physics	3	3	3
Physics 174, 175, 176 Laboratory	1	1	1
Approved General Education Subjects	3	3	3
	19	19	18

COLUMBIA UNIVERSITY
DEPARTMENT OF GEOLOGY

At Columbia University the Department of Geology, continuing its policy of rotating administrative duties, has elected Professor Walter H. Bucher to serve as Executive Officer for a period of three years. He succeeds Professor Paul F. Kerr whose term expired on June 30, 1950, and who held office during the difficult period of post-war reconstruction. Professor Marshall Kay has been elected Educational Coordinator and Professor Kerr Research Coordinator. These three officers will constitute an Executive Committee for the Department.

PATENTS*

4—ACCELEROMETER

U. S. No. 2,498, 118. D. Weiss. Iss. 2/21/50. App. 2/24/45.

Continuously Measuring Angular Accelerometer. An aircraft accelerometer having a pivoted beam held against rotation by coil springs and immersed in a viscous liquid, the beam carrying transformer cores whose motion varies the secondary voltage.

U. S. No. 2,498,997. W. B. McLean and I. H. Swift. Iss. 2/28/50. App. 10/27/48. Assign. U. S. A.

Photoelectric Inclinometer and Accelerometer. A tilt or acceleration indicator having a weight on a spring-controlled pivoted arm which obstructs light passing through a slit onto a photo-cell.

U. S. No. 2,499,667. A. N. Milster. Iss. 3/7/50. App. 5/3/45. Assign. Wagner Electric Corp.

Recording Decelerometer. A portable spring-driven recorder for recording the deceleration of a vehicle and also the brake-fluid pressure, the recording drum being automatically started by the application of brake pressure.

U. S. No. 2,500,548. R. Keller. Iss. 3/14/50. App. 9/6/44 and 8/29/45. Assign. Aktiengesellschaft Brown, Boveri & Cie.

Acceleration Meter. A device for indicating the angular acceleration of a rotating shaft having an a-c generator on the shaft connected to a condenser and inductance in series with a full-wave rectifier across the inductance and connected to a meter through a second condenser.

8—ACOUSTIC LOGGING

Application Ser. No. 578,531. A. Blanchard. Published 3/28/50. App. 2/17/45. Assign. Schlumberger Well Surveying Corp.

Method of and Apparatus for Obtaining Indications of the Specific Acoustic Resistance of Materials. An acoustic well-logging system in which a self-maintained resonant acoustic oscillator coupled to the well fluid is lowered into the well with the oscillator feedback obtained from a pickup on the diaphragm piston and passed through a phase shifter adjusted so as to overcome the resistive load on the piston and eliminate the quadrature component, the oscillation frequency of the oscillator being recorded at the surface.

U. S. No. 2,497,172. C. H. Kean. Iss. 2/14/50. App. 9/27/47. Assign. Standard Oil Development Co.

Means for Mounting Elongated Magnetostrictive Elements. A mounting for an oscillating magnetostrictive bar in which the bar is held at its midpoint by pins from a tapered ring which fits into a similarly tapered ring in the housing.

12—ACOUSTIC MEASUREMENTS

U. S. No. 2,494,643. J. F. Clark, III. Iss. 1/17/50. App. 11/21/46. Assign. Radio Corp. of America.

Volume Indicator System. A signal-level indicator in which the signal is connected across a voltage divider with low level taps to neon indicator lamps and with the signal also connected to a full-wave rectifier and to another voltage divider with signal lamps to indicate high levels.

U. S. No. 2,495,426. H. Schwartzberg. Iss. 1/24/50. App. 11/26/46.

Sound Control System. A sound-level control for a p-a system in which a supersonic signal is transmitted over the same acoustical path as the audio signal and the intensity level of both signals adjusted in accordance with the received supersonic signal.

* Abstracts by O. F. Ritzmann, Gulf Oil Corporation Patent Department.

U. S. No. 2,499,593. B. Kreuzer and I. R. Goshaw. Iss. 3/7/50. App. 3/17/43. Assign. Radio Corp of America.

Reverberation Time Measuring System. A reverberation-curve recording system in which an oscillator is connected to a loud speaker and one winding of a differential galvanometer and the pickup is connected through a noise-reduction and averaging amplifier to the other winding of the galvanometer.

U. S. No. 2,500,431. R. K. Potter. Iss. 3/14/50. App. 12/6/46. Assign. Bell Telephone Laboratories, Inc.

Visual Representation of Complex Waves. A system for obtaining a spectrogram of sounds by impressing the output of a microphone on a number of parallel band-pass filters whose outputs are applied through a smoothing network to a series of c-r tube electrodes which are swept by the c-r beam.

U. S. No. 2,500,646. R. R. Riesz. Iss. 3/14/50. App. 11/23/46. Assign. Bell Telephone Laboratories, Inc.

Visual Representation of Complex Waves. A system for visually portraying complex waves by passing the wave through parallel high-pass and low-pass filters and impressing the output of one filter on the horizontal sweep of a c-r tube and the output of the other filter on the vertical sweep.

U. S. No. 2,501,488. R. Adler. Iss. 3/21/50. App. 7/19/46. Assign. Zenith Radio Corp.

Magnetostrictively Driven Mechanical Wave Filter. A wave filter having a train of mechanically-coupled vibrators with a magnetostrictive transducer at each end of the train.

16—AIRPLANE FLIGHT INSTRUMENT

U. S. No. 2,493,931. M. E. Smaby. Iss. 1/10/50. App. 1/19/46. Assign. Boeing Airplane Co.

True Air-Speed Meter. An air-speed indicator having a motor-driven symmetrical airfoil propeller with symmetrical pressure taps on two sides of the propeller blade connected to a differential bellows with contacts which vary the motor speed so that the propeller has equal pressure on both sides.

U. S. No. 2,494,877. J. Idrac. Iss. 1/17/50. App. 12/31/45 and 12/30/46. Assign. Groupement Francais pour le Developpement des Recherches Aeronautiques.

Icing Indicator. A wing ice indicator having a small feeler which is oscillated over the wing surface, the feeler being driven through a spring arranged with electric contacts so that drag on the feeler caused by ice on the wing will actuate an alarm.

U. S. No. 2,496,674. A. C. Omberg. Iss. 2/7/50. App. 2/2/46. Assign. Bendix Aviation Corp.

System for Ground Speed Determination. A ground-speed indicator in which servo-motors follow the rectangular coordinates of the plane's position and the motor currents are passed through heaters having thermocouples whose emfs are added and indicated.

U. S. No. 2,497,431. W. W. Beman. Iss. 2/14/50. App. 9/8/44. Assign. Lockheed Aircraft Corp.

Critical Speed Indicator. A critical Mach-number indicator having in the wind stream a Pitot tube with static and dynamic openings which are connected to evacuated bellows mechanically coupled to give the ratio of absolute total pressure to absolute static pressure.

U. S. No. 2,497,494. G. L. Fleming. Iss. 2/14/50. App. 9/3/47.

Stall Warning Device for Airplanes. A slot in the leading edge of an airplane wing which produces a whistle when the air speed falls to an unsafe value.

U. S. No. 2,499,284. H. A. Smith. Iss. 2/28/50. App. 4/29/47.

Airplane Stall Indicator. A stall indicator having an air-pickup tube leading to a bubble tube under the surface of a liquid and a vane in the windstream which drops in front of the pickup tube when the speed decreases to an unsafe low value.

40—CABLE

U. S. No. 2,499,720. W. D. Boynton. Iss. 3/7/50. App. 11/30/45. Assign. Western Electric Co., Inc.

Method of and Apparatus for Testing Insulation. An apparatus for electrically testing the insulation of a multi-conductor cable by applying high voltage to each of the conductors in sequence and connecting the others to ground.

U. S. 2,501,558. F. J. Williams. Iss. 3/21/50. App. 3/7/49. Assign. Geophysical Service, Inc.

Coupling Means for Seismometers. A geophone having its coil coupled to a transformer core which extends outside the geophone case and is coupled to a loop taped into the cable conductor by a removable magnetic pin or by a mating magnetic core piece on the cable.

44—CALIPER LOGGING

U. S. No. 2,497,990. T. A. Huber and G. E. Cannon. Iss. 2/21/50. App. 11/30/46. Assign. Standard Oil Development Co.

Apparatus for Logging Boreholes. A device for determining the thickness of mud sheath and having two sets of arms urged outward by springs and actuating rheostats whose currents are separately recorded at the surface, one set of arms having skids which ride on the mud sheath and the other set of arms having cutting wheels which cut through the mud to the formation.

48—CASING PERFORATOR

U. S. No. 2,494,256. M. Muskat, F. W. Parker and W. L. Kehl. Iss. 1/10/50. App. 9/11/45. Assign. Gulf Research & Development Co.

Apparatus for Perforating Well Casings and Well Walls. A casing-perforating tool using a shaped explosive charge with a cavity which produces an explosive jet.

64—COMMUNICATION DEVICE

U. S. No. 2,499,195. J. A. McNiven. Iss. 2/28/50. App. 5/10/46.

Mine Communication System. A communication system in which an f-m transmitter is connected through an impedance-matching unit to two spaced electrodes in the earth and an f-m receiver connected through an impedance-matching unit to two receiving electrodes.

68—COMPUTING DEVICE

U. S. No. 2,494,036. S. Darlington. Iss. 1/10/50. App. 9/20/47. Assign. Bell Telephone Laboratories, Inc.

Differential Analyzer. An apparatus for solving a differential equation in a single variable having two voltage sources connected to differentiators which perform the operations indicated and a summing amplifier whose output controls one of the voltage sources.

U. S. No. 2,496,723. J. A. Hipple, Jr. Iss. 2/7/50. App. 4/27/44 and 10/22/46. Assign. Westinghouse Electric Corp.

Logarithmic Amplifier. A logarithmic amplifier system having a linear amplifier whose output is connected to an exponential feedback amplifier and also to a linear feedback amplifier, with the outputs of both feedback amplifiers in series with the input to the first amplifier.

U. S. No. 2,497,208. N. D. Coggeshall. Iss. 2/14/50. App. 8/27/48. Assign. Gulf Research & Development Co.

Electrical Logarithm Computer. A logarithmic potentiometer having a uniform circular disc with radial current flow and a radially-adjustable contact sliding over the surface of the disc.

U. S. No. 2,497,883. H. Harris, Jr. Iss. 2/21/50. App. 1/28/43. Assign. The Sperry Corp.

Electronic Computer. An electronic multiplying device in which two signals representing the factors are fed into an amplifier at different frequencies and the amplifier output filtered and one frequency used to control the amplification.

U. S. No. 2,497,913. R. H. Rines. Iss. 2/21/50. App. 4/2/47.

Range and Elevation Computing System. A computer for obtaining the horizontal range and height of an airplane from the radar range and elevation angle.

U. S. No. 2,500,997. T. D. Morgan. Iss. 3/21/50. App. 7/13/44. Assign. Phillips Petroleum Co.

Electrical Computing Device. A network for solving the linear simultaneous equations obtained in infra-red absorption spectroscopy by the iteration method.

U. S. No. 2,501,058. V. Klasek. Iss. 3/21/50. App. 3/13/47 and 2/17/48.

Connection for Solving the Relation of Several Variables. A system for obtaining a signal related to the setting of four potentiometers by connecting them in two pairs of series circuits with half-wave rectifiers, an a-c being applied to the sliders of the outside potentiometers and an indicator or controller to the sliders of the inside potentiometers.

U. S. No. 2,502,360. S. B. Williams. Iss. 3/28/50. App. 3/14/47. Assign. Bell Telephone Laboratories, Inc.

Electronic Computer. An electronic digital computer using thyratrons connected in flip-flop circuits forming closed rings or open chains through which a steep pulse progresses.

76—CONTINUOUS WAVE SEISMIC TESTING

U. S. No. 2,496,632. B. J. Lazan. Iss. 2/7/50. App. 12/14/44. Assign. The Baldwin Locomotive Works.

Vibration Testing Apparatus. A continuous-wave testing apparatus using a motor-driven mechanical vibrator whose speed is controlled from the pickup amplifier so as to maintain a predetermined amplitude of vibration in the test structure.

U. S. No. 2,501,158. F. E. Chilcott. Iss. 3/21/50. App. 9/20/48. Assign. Viber Co.

Form Vibrator. A concrete vibrator having a compressed-air motor directly connected to a rotor with an eccentric weight.

80—CORE BARREL

U. S. No. 2,494,363. B. W. Sewell. Iss. 1/10/50. App. 12/21/39 and 12/23/44. Assign. Standard Oil Development Co.

Core Barrel. A wire-line operated pressure core barrel having an outer barrel which latches onto the lower end of the drill stem and an inner core-taking barrel which is raised when the device is removed so as to close a valve and unlatch the outer barrel.

U. S. No. 2,499,543. L. E. Townsend. Iss. 3/7/50. App. 9/17/46.

Core Lifting Arrangement for Deep Well Drills. A core catcher for a core barrel having at its lower end a split ring tapered to fit the inside taper of the drill bit and having upwardly-extending spring fingers which are bent inward to grip the core.

84—CORE ORIENTATION

U. S. No. 2,496,422. P. Subkow. Iss. 2/7/50. App. 5/3/43.

Geometrical Determination of Dip and Strike of Cored Strata. A method of core orientation in which two cores are taken from the same or parallel strata but at different deviations in the same or adjacent holes and the orientation geometrically determined from the differential deviation.

U. S. No. 2,500,680. H. N. Herrick and W. M. Schaufelberger. Iss. 3/14/50. App. 12/6/47. Assign. California Research Corp.

Method and Apparatus for Determining Magnetic Properties of Well Cores. A core-orientation apparatus having a pair of rapidly-rotating coils connected in opposition and with the core arranged to be rotated into different azimuths adjacent to one of the coils and the induced emf measured.

92—DRILL

U. S. No. 2,493,178. E. B. Williams, Jr. Iss. 1/3/50. App. 6/3/46.

Drill Bit. A rotary bit having a matrix whose bottom and sides carry hard inserts and have recesses to allow the mud to circulate, the bottom of the drill having a slightly eccentric conical recess which cuts out the center of the hole.

U. S. No. 2,499,252. G. L. Michael. Iss. 2/28/50. App. 12/26/47.

Earth Boring Tool. An expanding bit having pivoted cutters which are moved outward by springs but which retract when pulled up against the bottom of the casing.

U. S. No. 2,499,282. W. A. Roberts. Iss. 2/28/50. App. 7/11/46.

Rock Bit. A drill bit having outwardly-extending cutters with lower and upper cutting edges so as to break up rocks that fall into the hole above the bit.

U. S. No. 2,500,785. A. Arutunoff. Iss. 3/14/50. App. 7/8/46.

Side Drill with Slotted Guide Tube. A side-wall drill having a casing containing a slotted guide tube with a curved section to deflect a drill in the tube into the side wall, the drill being driven by a motor through gears which mesh at the slot of the guide tube.

U. S. No. 2,501,411. M. A. Ryan. Iss. 3/21/50. App. 10/27/47. Assign. Phillips Petroleum Co.

Combination Well Tool. A combined drill and jetting tool having the drill bit on a short sliding keyed shaft with radial holes which partially cut off the drill circulation when the drill stem is lifted so that fluid is forced out through holes in the stem at high pressure.

U. S. No. 2,502,128. J. C. Curtis. Iss. 3/28/50. App. 4/30/48. Assign. Joy Manufacturing Co.

Rock Drill Bit. A percussion bit having diametral grooves with hard inserts held in place by a tongue which is brazed to a central retaining ring.

100—DRILLING RATE RECORDER

U. S. No. 2,494,092. J. T. Hayward. Iss. 1/10/50. App. 8/29/44.

Apparatus for Logging Wells in Terms of Drilling Rates. A drilling-rate recorder having an averaging mechanism controlled by the speed of rotation and the vertical feed so as to smooth out sudden increments in apparent depth.

108—ECHO SOUNDING

U. S. No. 2,499,520. P. M. Modlowski and A. M. Skudre. Iss. 3/7/50. App. 1/31/47. Assign. Raytheon Manufacturing Co.

Distance Measuring Device. An echo distance-measuring apparatus in which the transmitted and received pulses are applied to a vacuum tube and a gas tube in series so that the transmitted pulse

establishes conductivity to a condenser and the reflected pulse cuts off the current and the charge is indicated on a meter.

U. S. No. 2,501,236. W. R. Ryan and S. Levine. Iss. 3/21/50. App. 2/26/45. Assign. Bendix Aviation Corp.

Depth Sounding Recorder. An echo-sounding recorder having a ring which is rotated continuously in synchronism with the signals and which carries the recording stylus across the tape so that the record may be observed through the hole in the ring.

116—ELECTRIC LOGGING

U. S. No. 2,501,953. P. W. Martin. Iss. 3/28/50. App. 5/22/45.

Electrical Well Logging System. A well-logging system using a low frequency for logging and a high frequency for recording, the high frequency being modulated by the positive half-cycles of the low frequency for one logging parameter and by the negative half-cycles of the low frequency for a second logging parameter, with the two parameters' signals separated by rectifiers at the surface.

124—ELECTRICAL PROSPECTING

U. S. No. 2,502,059. B. C. Muzzey. Iss. 3/28/50. App. 2/4/47. Assign. General Motors Corp.

Sheet Thickness Gauge. A device for determining the thickness of sheet or of a hollow article by passing a direct current from a remote electrode to an electrode at the point of measurement and observing the difference in potential between two sets of electrodes located at different radial distances from the point of measurement.

136—EXPLOSIVE

U. S. No. 2,495,868. J. T. Power. Iss. 1/31/50. App. 1/30/46. Assign. Atlas Powder Co.

Detonator. An electric blasting cap having a primer charge and a base charge of completely nitrated dextrose catalytic polymer.

U. S. No. 2,499,321. G. A. Lyte. Iss. 2/28/50. App. 8/24/46. Assign. Trojan Powder Co.

Explosive Composition. An ammonium nitrate explosive containing a mixture of pentolite and trinitrotoluene as a sensitizer.

U. S. No. 2,499,440. I. C. Wood. Iss. 3/7/50. App. 1/27/45. Assign. The Denver Fire Clay Co.

Sheath for Explosives. A flame-quenching sheath for an explosive cartridge molded in the form of cylindrical segments joined along their edges so that the segments may be broken apart and placed around the cartridge.

140—FLAW DETECTOR

U. S. No. 2,494,990. R. B. De Lano, Jr. Iss. 1/17/50. App. 6/27/47. Assign. Sperry Products, Inc.

Method and Means for Locating Discontinuities by Pulses of Radiant Energy. A supersonic inspection system having a depth-indicating meter in which the meter amplifier is made inoperative during transmission by a connection to the pulse generator and also inoperative during receipt of the reflection from the bottom of the specimen by a connection to a delayed pulse generator.

U. S. No. 2,497,855. W. C. Barnes, H. W. Keevil and J. C. Dionne. Iss. 2/21/50. App. 1/17/44.

Flaw Detecting Method and Apparatus for Ferromagnetic Bodies. A rail flaw detector in which the rail is magnetized with an L-shaped pole piece and partially demagnetized with a magnetic follower so that the longitudinal magnetization is reduced so as to increase the indication of deep-lying flaws.

U. S. No. 2,497,856. W. C. Barnes and H. W. Keevil. Iss. 2/21/50. App. 7/21/45.

Apparatus and Method for Detecting Flaws in Magnetizable Bodies. A rail flaw detector having a magnetizing pole piece which contacts the side of the rail so that burns on the running face will not be indicated.

U. S. No. 2,499,459. B. Carlin. Iss. 3/7/50. App. 10/4/47. Assign. Sperry Products, Inc.

Resonance Device for Inspecting Materials. A supersonic inspection system in which a piezoelectric crystal transmits vibrations into the material and the crystal is excited by an oscillator having a variable reactance tube connected to a sweep circuit to vary the oscillator frequency.

U. S. No. 2,499,720. W. D. Boynton. Iss. 3/7/50. App. 11/30/45. Assign. Western Electric Co., Inc.

Method of and Apparatus for Testing Insulation. An apparatus for electrically testing the insulation of a multi-conductor cable by applying high voltage to each of the conductors in sequence and connecting the others to ground.

U. S. No. 2,502,059. B. C. Muzzey. Iss. 3/28/50. App. 2/4/47. Assign. General Motors Corp.

Sheet Thickness Gauge. A device for determining the thickness of sheet or of a hollow article by passing a direct current from a remote electrode to an electrode at the point of measurement and observing the difference in potential between two sets of electrodes located at different radial distances from the point of measurement.

148—FLOW METER

U. S. No. 2,494,673. G. A. Smith. Iss. 1/17/50. App. 10/9/45.

Fluid Metering or Control System. A flow meter having a low fluid resistance and a high fluid resistance in series and an auxiliary pump to recirculate the fluid through the low resistance and through a flow indicator, the pump speed being automatically controlled to maintain the same pressure drop across the low resistance as across the high resistance.

U. S. No. 2,494,781. E. F. Stover. Iss. 1/17/50. App. 9/29/44.

Fluid Meter. A flow meter using a Venturi tube whose pressure difference controls a balance which affects the air flow from an auxiliary air supply through a pilot valve and the air pressure indicated.

U. S. No. 2,497,978. H. M. Carlson. Iss. 2/21/50. App. 1/12/46. Assign. Bituminous Coal Research, Inc.

Orifice Plate. An orifice-type flow meter for solid-gas mixtures in which the down-stream side of the orifice plate is faced with rubber so that solid particles will bounce off instead of sticking to the plate.

U. S. No. 2,501,705. C. T. Beggs. Iss. 3/28/50. App. 9/8/48.

Apparatus for Measuring Liquid Flow. A device for measuring velocity of flow in an open channel and which floats on a vertical guide rod and has a weighted impact paddle connected to the arm of a rheostat connected in an indicator circuit.

164—GAMMA RAY LOGGING

U. S. No. 2,493,346. G. Herzog. Iss. 1/3/50. App. 8/29/46. Assign. The Texas Co.

Well Logging Detector Calibration. A system for correcting a gamma-ray logging apparatus for temperature variations by recording the signal from an auxiliary detector which is close to a radioactive source in the apparatus or by recording the ratio between its output and that of the logging detector.

168—GAS ANALYSIS

U. S. No. 2,499,020. R. E. Fearon. Iss. 2/28/50. App. 3/31/44. Assign. Stanolind Oil and Gas Co.

Gas Analysis. A system of gas analysis in which a shutter opens the inlet to a long tube at low pressure and the time of arrival of various components at the other end of the tube observed with an ionization gauge.

U. S. No. 2,499,626. J. R. Bowman. Iss. 3/7/50. App. 4/30/47. Assign. Gulf Research & Development Co.

Dipole Moment Indicator and Control Method. Apparatus for indicating the dipole moment of a gas by using it as the dielectric of two similar condensers maintained at different temperatures but at the same gas density, and observing the difference in capacities by a beat-frequency method.

180—GRAVIMETER

U. S. No. 2,497,594. A. D. Fialkow. Iss. 2/14/50. App. 12/26/46. Assign. Control Instrument Co., Inc.

Stable Vertical. A vertical-direction indicator having a pointer mounted on a gimbal support and also having an auxiliary short control pendulum on a separate gimbal mounting which actuates potentiometers whose outputs are connected through low-pass filters to servo-motors on the indicator gimbals and with the control-pendulum gimbals locked during accelerations and turns.

U. S. No. 2,497,607. D. L. Herr. Iss. 2/14/50. App. 12/26/46. Assign. Control Instrument Co., Inc.

Stable Vertical. A vertical-direction indicator having a pointer mounted on a gimbal support and also having an auxiliary control pendulum on a separate gimbal mounting which actuates potentiometers whose outputs are connected to averaging devices and to servo-motors on the indicator gimbals and with the control-pendulum gimbals locked during accelerations and turns.

U. S. No. 2,497,614. E. E. Libman. Iss. 2/14/50. App. 1/10/47. Assign. Control Instrument Co., Inc.

Stable Vertical. A vertical-direction indicator having a gyro mounted on a gimbal support and also having an auxiliary control pendulum on a separate gimbal mounting which actuates potentiometers whose outputs cause precession of the gyro and with the control-pendulum gimbals locked and disconnected from the gyro during accelerations and turns.

188—HYGROMETER

U. S. No. 2,501,377. R. H. Cherry. Iss. 3/21/50. App. 7/27/45. Assign. Leeds and Northrup Co.

Relative Humidity Measuring System. A hygrometer having two thermal conductivity cells one of which determines the absolute humidity and the other the absolute humidity at saturation, and with the cells connected in a network for indicating the ratio.

192—INCLINOMETER

U. S. No. 2,493,946. G. Craft and V. G. Carlson. Iss. 1/10/50. App. 12/18/47.

Gradometer. A grade indicator having a pendulum in a liquid-filled chamber and connected by a cam to a pointer.

U. S. No. 2,498,083. R. A. Kennedy and C. A. Harms. Iss. 2/21/50. App. 7/10/48.

Pocket Clinometer. A portable inclinometer having a pivoted pendulum with a pointer and scale.

U. S. No. 2,498,997. W. B. McLean and I. H. Swift. Iss. 2/28/50. App. 10/27/48. Assign. U. S. A.

Photoelectric Inclinometer and Accelerometer. A tilt or acceleration indicator having a weight on a spring-controlled pivoted arm which obstructs light passing through a slit on to a photocell.

196—INFRARED MEASUREMENTS

U. S. No. 2,497,129. M. D. Liston. Iss. 2/14/50. App. 5/2/47. Assign. The Perkin-Elmer Corp.

Radiation Detecting Apparatus. An infrared detecting system in which the beam to a thermopile is slowly interrupted and the thermopile signal amplified by a vibrator in the input of an amplifier with a synchronous vibrator in its output and also having a d-c feedback circuit.

U. S. No. 2,502,319. M. J. E. Golay. Iss. 3/28/50. App. 4/30/48.

Method and Apparatus for Measuring Radiation. An infrared spectrometer in which the unknown beam and the standard beam are synchronously chopped at adjustable phase and the detector currents combined and rectified and indicated.

200—LEVEL INDICATOR

U. S. No. 2,495,416. C. R. McCauley. Iss. 1/24/50. App. 6/7/45.

Liquid Level Indicator. A float-type liquid level indicator in which the float arm is connected through bellows to a multi-contact selector switch and indicators.

U. S. No. 2,496,366. S. L. Adelson. Iss. 2/7/50. App. 10/25/46. Assign. Infilco Inc.

Liquid Level Gauge. A liquid-level indicator having two oppositely-rotating motors connected to a differential gearing so that the sum controls the indicator and float position, and with one motor controlled by an above-level detector and the other controlled by an under-level detector so that the liquid level is followed.

U. S. No. 2,497,694. S. Shakin. Iss. 2/14/50. App. 9/14/48. Assign. Nathan Manufacturing Co.

Tank Gauge. A liquid-level indicator having a spring which supports a long vertical sinker whose change in buoyancy due to change in the amount of immersion is indicated on a dial.

U. S. No. 2,498,232. J. M. Andrews. Iss. 2/21/50. App. 5/10/48. Assign. York Corp.

Electrical Liquid Level Control. A water-level control for a tank having three electrodes which dip into the water at the corners of an equilateral triangle and are connected so that when all three electrode circuits are open a relay-controlled valve admits more water.

224—MAGNETIC RECORDER

U. S. Re. No. 23,192. (Orig. No. 2,372,810). M. Camras. Iss. 1/31/50. App. 10/14/42, 4/3/45 and 1/12/49. Assign. Illinois Institute of Technology.

Constant Speed Drive for Magnetic Recorders. A magnetic wire drive in which the wire makes a separate loop around the driving pulley and several idler pulleys, and the take-up reel is driven through a slip clutch.

U. S. No. 2,493,742. S. J. Begun and M. D. Temple. Iss. 1/10/50. App. 8/22/45 and 7/30/46. Assign. The Brush Development Co.

Magnetic Transducing Core for Magnetic Record Transducers. A magnetic wire recorder having an a-c biasing flux and a guide about the pole piece to keep the wire in contact with a thin core only near the gap.

U. S. No. 2,495,125. O. R. Nemeth. Iss. 1/17/50. App. 8/16/47.

Wire Recorder Turret. A turret device for a wire recorder which threads the wire through the translating head and driving pulley and level wind pulley.

U. S. No. 2,496,047. D. R. Goddard. Iss. 1/31/50. App. 6/18/47. Assign. Radio Corp. of America.

Art of Recording and Reproducing Two-Sided Magnetic Records. An endless magnetic paper tape record having a half twist and magnetized at an angle so as to eliminate interference from the record on the opposite side of the paper.

U. S. No. 2,496,103. J. Neufeld. Iss. 1/31/50. App. 9/14/44.

Indexing and Speed Control System for Magnetic Reproducers. A magnetic recorder in which the speed of the tape-driving motor is controlled by the difference in speed between a motor driven from a standard frequency signal and one driven from a signal obtained from the tape through a low-pass filter.

U. S. No. 2,496,441. M. Camras. Iss. 2/7/50. App. 3/9/46. Assign. Armour Research Foundation of Illinois Institute of Technology.

Magnetic Recording Apparatus. A magnetic recording head whose pole-piece yoke has an insulating insert and with the pole pieces connected to a high-frequency supply so that the wire carries a high-frequency current and is subjected to a circular high-frequency alternating field while recording.

U. S. No. 2,497,654. S. J. Begun. Iss. 2/14/50. App. 4/29/45. Assign. The Brush Development Co.

System for Magnetically Recording a Modulated Carrier in Push-Pull. A magnetic recording system in which two tracks are placed side by side on a saturated magnetic tape, the tracks being of the modulated-carrier type with the envelope of one track giving one side of the signal and the envelope of the other track giving the other side of the signal.

U. S. No. 2,498,423. H. A. Howell. Iss. 2/21/50. App. 4/17/47. Assign. Indiana Steel Products Co.

Means for Demagnetizing High Coercive Force Materials. An erasing device for a magnetic record having two opposed C-shaped cores between which the record passes with the cores excited by low-frequency a-c.

U. S. No. 2,498,746. J. B. Walker. Iss. 2/28/50. App. 12/19/44.

Magnetic Sound Recording Apparatus. A magnetic tape recorder in which the tape is loosely wound on a rotating reel and the recording head has a pair of slender pole pieces which engage the two sides of the tape between convolutions.

U. S. No. 2,499,700. R. J. Tinkham and R. L. Landon. Iss. 3/7/50. App. 12/30/47. Assign. Magnecord, Inc.

Magnetic Recording and Reproducing Apparatus. A magnetic recorder using an endless magnetic tape which is contained in a magazine in folded layers and has part of the loop outside the magazine between inlet and outlet slits.

U. S. No. 2,499,895. J. B. Walker. Iss. 3/7/50. App. 10/8/45.

Magnetic Recording Apparatus. A magazine for a magnetic tape recorder having two spools and an internal pole piece and an external pole piece and recording head.

U. S. No. 2,500,903. M. A. Neff. Iss. 3/14/50. App. 8/2/45. Assign. Wirecorder Corp.

Magnetic Wire Sound Recording and Reproducing Apparatus. A magnetic recorder in which the reel spindles are driven by rollers arranged to wind up the wire on the respective reel and either reel spindle may be brought into engagement with its drive.

U. S. No. 2,501,126. H. A. Howell. Iss. 3/21/50. App. 10/18/46. Assign. The Indiana Steel Products Co.

Magnetic Record Medium. A magnetic record made of a high-permeability disc with a non-

magnetic coating which is cut with a spiral groove and with a high-coercive-force material at the bottom of the groove.

U. S. No. 2,501,573. D. B. McLouth, M. A. Neff and W. P. Haboush. Iss. 3/21/50. App. 2/14/45. Assign. Wirecorder Corp.

Magnetic Wire Sound Recording and Reproducing Apparatus. A magnetic wire recorder having two pulleys between which the wire passes, the pulleys being shifted after the magazine is in place so that the wire passes partially around each pulley, and with one of the pulleys driven at constant speed.

228—MAGNETIC TESTING

U. S. No. 2,495,544. R. A. Peterson, D. F. Heckle and J. E. Clarke. Iss. 1/24/50. App. 9/6/46. Assign. Magnaflux Corp.

Pipe Welding and Magnetic Testing Apparatus. A device for magnetizing the joint of welded pipe and having an arm extending inside the pipe with a roller which is urged outward by a spring and carries a magnetizing coil.

U. S. No. 2,495,545. R. A. Peterson, D. F. Heckle and J. E. Clarke. Iss. 1/24/50. App. 9/6/46. Assign. Magnaflux Corp.

Magnetic Particle Inspection Apparatus and Method. A device for continuous magnetic-particle testing of longitudinal pipe welds in which the weld is magnetized by a magnetic roller inside the pipe and a magnetic powder sprinkled on the outside of the weld and the excess powder blown off in a direction opposite to the movement of the pipe.

232—MAGNETOMETER

U. S. No. 2,493,779. J. H. Rubenstein. Iss. 1/10/50. App. 2/5/45.

Magnetometer. A mechanical magnetometer having a pair of cylindrical magnetic antenna members between which is pivoted a magnetic vane with hairspring and pointer.

U. S. No. 2,501,538. W. Ruska. Iss. 3/21/50. App. 4/9/45. Assign. Ruska Instrument Corp.

Magnetic Measuring Instrument. A Schmidt balance type of vertical field magnetometer for use at a base station and having a reflecting prism on the balance beam.

U. S. No. 2,501,598. G. C. Eltenton and M. B. Fallgatter. Iss. 3/21/50. App. 7/28/47. Assign. Shell Development Co.

Magnetic Method of Pipe-line Inspection. A system for determining the electric current in a buried pipe line by measuring the magnetic field with a magnetic gradiometer.

236—MASS SPECTROMETRY

U. S. No. 2,498,841. L. D. P. King. Iss. 2/28/50. App. 6/1/45. Assign. U. S. A.

Ion Source. An ion source for a cyclotron having a frusto-conical chamber with an opening and deflector at its apex, the gas being introduced into the chamber through a capillary and the ionizing potential applied between the filament and the chamber wall.

U. S. No. 2,499,288. J. G. Backus. Iss. 2/28/50. App. 7/2/47. Assign. U. S. A.

Vacuum Analyzer. A mass spectrometer having an anode in the form of a slit tube with cathodes at each end of the tube and the ion-accelerating slit opposite the slit in the anode tube and two ion-collecting slits at distances in the ratio of $1/\sqrt{5}$, the entire assembly being in a magnetic field.

U. S. No. 2,499,289. J. G. Backus. Iss. 2/28/50. App. 7/2/47. Assign. U. S. A.

Ion Generator. An intense ion source having a tube with a longitudinal outlet slit and cathodes at each end of the tube and a pusher electrode in the tube opposite the slit.

U. S. No. 2,499,320. R. Loevinger. Iss. 2/28/50. App. 6/23/47. Assign. U. S. A.

Ion Generator. A focusing ion source having a semicylindrical rear anode and a flat front anode with a longitudinal slit and cathodes at each end of the semicylinder and an external accelerating plate with a slit opposite the slit in the front anode.

248—MOTION TESTING

U. S. No. 2,498,045. C. T. G. Looney, L. G. Howell and B. G. Johnston. Iss. 2/21/50. App. 8/15/46. Assign. U.S.A.

Deceleration Apparatus. An apparatus for decelerating projectiles in which the gun is fired into a tube having pressure detectors connected so as to turn on a blast of compressed air against the projectile.

252—MUD LOGGING

U. S. No. 2,497,990. T. A. Huber and G. E. Cannon. Iss. 2/21/50. App. 11/30/46. Assign. Standard Oil Development Co.

Apparatus for Logging Boreholes. A device for determining the thickness of mud sheath and having two sets of arms urged outward by springs and actuating rheostats whose currents are separately recorded at the surface, one set of arms having skids which ride on the mud sheath and the other set of arms having cutting wheels which cut through the mud to the formation.

276—PERMEABILITY TESTING

U. S. No. 2,498,198. C. M. Beeson. Iss. 2/21/50. App. 12/14/46. Assign. Socony-Vacuum Oil Co., Inc.

Method of Measuring Permeability. A method of measuring the permeability of a cylindrical core by placing it in a tightly-fitting tube, packing sand against the ends of the core, covering each end with a sponge-rubber disc and passing fluid through the system.

288—PRESSURE GAUGE

U. S. No. 2,494,570. G. R. Mezger. Iss. 1/17/50. App. 1/22/46.

Electrical Transducer. An engine-pressure indicator having a hollow metal cylinder with a flexible diaphragm at one end and connected as a resonant cavity in an ultra-high-frequency circuit.

U. S. No. 2,494,621. H. S. Jones. Iss. 1/17/50. App. 8/30/45. Assign. Thomas A. Edison, Inc.

Pressure-Responsive Variable Resistance Device, A pressure gauge having a bellows with an arm which is mechanically connected to the mid-point of a pile of annular pressure-sensitive plates in an indicator circuit.

U. S. No. 2,495,314. W. I. Caldwell. Iss. 1/24/50. App. 7/16/47. Assign. Taylor Instrument Companies.

Bourdon Spring and Load Element. A Bourdon tube made by flattening a tube so that the side walls are nearly in contact and with removable wires in the edges to form circular margins.

U. S. No. 2,496,337. D. R. de Boisblanc. Iss. 2/7/50. App. 2/29/44. Assign. Phillips Petroleum Co.

Detonation Meter. A knock meter for an internal-combustion engine having a pressure pickup connected to a high-pass filter, amplifier, threshold and pulse former, a predetermined number of pulses being accumulated into larger pulses which are discharged through an indicator.

U. S. No. 2,496,338. H. M. Barton, Jr. Iss. 2/7/50. App. 1/18/45. Assign. Phillips Petroleum Co.

Detonation Indicator Circuit and Method. A knock meter for an internal combustion engine having a pressure pickup connected to a circuit which accumulates a predetermined number of knock impulses on a condenser which is discharged to other condensers and eventually to an indicator when the next to last pulse of a group is received by the preceding condenser.

U. S. No. 2,497,213. J. R. O. Downing. Iss. 2/14/50. App. 5/22/45. Assign. National Research Corp.

Pressure Gauge. A vacuum gauge having a casing which forms an ionization chamber and contains radioactive material and with the ionization current indicated.

U. S. No. 2,497,974. M. E. Bourns. Iss. 2/21/50. App. 9/27/49.

Pressure Responsive Rheostat. A pressure gauge having a Bourdon tube whose free end engages the arm of a rheostat through a motion-amplifying linkage.

304—RADIOACTIVITY LOGGING

U. S. No. 2,493,535. G. Herzog. Iss. 1/3/50. App. 3/17/45. Assign. The Texas Co.

Voltage Control and Stabilizing Circuits. A temperature compensator for the anode voltage of a radioactivity well-logging detector using a voltage divider of two resistors with different temperature coefficients.

U. S. No. 2,493,536. G. Herzog. Iss. 1/3/50. App. 3/17/45 and 1/29/49. Assign. The Texas Co.

Voltage Control and Stabilizing Circuits. A temperature compensator for the anode voltage of a radioactivity well-logging detector using a potentiometer whose slider is controlled by a bimetallic thermostatic element.

U. S. No. 2,495,736. S. Krasnow and L. F. Curtiss. Iss. 1/31/50. App. 10/24/39 and 3/3/42. Assign. S. Krasnow.

Radiant Energy Activation. A radioactivity logging system in which a radioactive gas or salt which is selectively absorbed by petroleum is introduced into the well and the material located with a radioactivity detector.

U. S. No. 2,495,781. D. Silverman. Iss. 1/31/50. App. 11/13/47. Assign. Stanolind Oil and Gas Co.

Shield for Well Logging Instruments. A radioactive source for a radioactivity-logging device which has a heavy cylindrical shield held on a shoulder of the capsule which contains the radioactive material, the shield remaining on top of the well pipe when the capsule is lowered into the well and picked up again when the capsule is taken out of the well.

308—RADIOACTIVITY MEASUREMENTS

U. S. No. 2,493,935. C. E. Wiegand and E. G. Segre. Iss. 1/10/50. App. 3/15/48. Assign. U.S.A.

High-Energy Neutron Counter. A neutron counter having a number of parallel-disc electrodes in an argon-filled chamber with the discs coated with a thin layer of bismuth.

U. S. No. 2,494,641. H. L. Anderson and P. G. Koontz. Iss. 1/17/50. App. 4/12/45. Assign. U.S.A.

Radiation Counter. A Geiger-Muller counter having a thin aluminum tube with thick end portions and a central wire anode.

U. S. No. 2,496,123. J. K. East and S. G. English. Iss. 1/31/50. App. 1/9/46. Assign. U.S.A.

Ionization Chamber. An ionization chamber having a removable sample holder which is covered by an interchangeable screen, the sample holder and screen holder being mounted on the end closure of the chamber.

U. S. No. 2,496,886. E. W. Molloy and W. H. Hinch. Iss. 2/7/50. App. 8/9/46. Assign. U.S.A.

Radiation Alarm and Measurement Device. A circuit for a portable radioactivity measuring device using an ionization chamber and an electrometer tube connected as a vacuum tube voltmeter with a glow-discharge relaxation oscillator in its plate circuit.

U. S. No. 2,497,823. E. W. Molloy. Iss. 2/14/50. App. 6/10/46. Assign. U.S.A.

Radiation Measuring Device for Air Filters. A device for measuring the radioactivity of dust in which the air is drawn through filter paper with an adjacent grid and insulated plate and the ionization current measured.

U. S. No. 2,498,461. A. M. Skellett. Iss. 2/21/50. App. 8/3/48. Assign. National Union Radio Corp.

Detector for High Energy Radiation. A device for detecting high energy radiation having a cavity resonator connected to an ultra-high-frequency generator with one wall of the resonator pervious to the radiation and having a coating which emits secondary electrons.

U. S. No. 2,498,841. L. D. P. King. Iss. 2/28/50. App. 6/1/45. Assign. U.S.A.

Ion Source. An ion source for a cyclotron having a frusto-conical chamber with an opening and deflector at its apex, the gas being introduced into the chamber through a capillary and the ionizing potential applied between the filament and the chamber wall.

U. S. No. 2,499,311. G. Herzog and K. C. Crumrine. Iss. 2/28/50. App. 3/28/47. Assign. The Texas Co.

Neutron Detection. A device for detecting neutrons in the presence of gamma rays and having a central wire anode surrounded by three cylindrical cathodes, the first one being grounded, the second one maintained at a low potential and the third at a high potential, and with the anode connected to a pre-amplifier and recorder.

U. S. No. 2,499,489. L. Goldstein and B. Pregel. Iss. 3/7/50. App. 1/24/44. Assign. Canadian Radium & Uranium Corp.

Exploring for Radioactive Bodies. Apparatus for airborne radioactivity prospecting having a large ionization chamber with a cylindrical metal envelope, a conducting screen and an axial anode wire and filled with argon under pressure, the screen being maintained more negative than the envelope so as to extract ions from the space between the envelope and the screen, and the current between the screen and the anode being detected.

U. S. No. 2,499,830. E. W. Molloy. Iss. 3/7/50. App. 11/21/46. Assign. U.S.A.

Air Proportional Counter. An alpha-particle counter having a tubular screen cathode exposed to atmospheric air and a central wire anode.

U. S. No. 2,499,889. C. F. Teichmann. Iss. 3/7/50. App. 5/30/45. Assign. Texaco Development Corp.

Control System for Closure Means. A system for opening and closing doors using a source of penetrating radiation and a detector which actuates relays.

U. S. No. 2,499,953. G. Herzog. Iss. 3/7/50. App. 5/27/44. Assign. The Texas Co.

Linear Integration Meter. A counting-rate meter having a Geiger-Muller tube connected to an R-C integration circuit with an adjustable bucking potential on the condenser and balance indicated with an electronic voltmeter.

U. S. No. 2,500,941. H. Friedman. Iss. 3/21/50. App. 3/7/46.

Geiger-Mueller Counter Structure. A detecting element for a radiographic exposure meter having a central wire anode and a coaxial cylindrical cathode whose surface has a coating of photosensitive silver halide.

U. S. No. 2,501,173. G. Herzog. Iss. 3/21/50. App. 7/12/45. Assign. The Texas Co.

Device for Measuring Thickness. A device for measuring the wall thickness of a hollow object and having a pantograph frame with an arm for holding a radioactive source which can be inserted into the object and another arm which holds a gamma-ray detector on the outside opposite the source, the detected intensity being indicated.

U. S. No. 2,501,174. G. Herzog. Iss. 3/21/50. App. 7/12/45. Assign. The Texas Co.

Radioactive Measuring. A device for measuring the wall thickness of a hollow object and having a pantograph frame with an arm for holding a radioactive source against the inside surface and another arm which holds a gamma-ray detector against the outside surface opposite the source, the detected intensity being indicated.

U. S. No. 2,501,560. M. Blau. Iss. 3/21/50. App. 4/26/47. Assign. Canadian Radium & Uranium Corp.

Apparatus for Indicating and Measuring Small Movements. A transducer having a moving screen with progressively-graduated amounts of a radioactive material and a stationary radioactivity detector whose output is indicated.

U. S. No. 2,502,331. L. Malter. Iss. 3/28/50. App. 12/21/48. Assign. Radio Corp. of America.

Geiger-Muller Counter for Radioactive Emission. A Geiger-Muller counter having an indirectly-heated cathode which is maintained at a temperature below that of thermionic emission and which eliminates spurious counts.

312—RADIO NAVIGATION

U. S. No. 2,493,097. I. Wolff. Iss. 1/3/50. App. 3/20/41. Assign. Radio Corp. of America.

Position Finder. A radio position-finding system in which pulses are emitted from a mobile transmitter and returned at different frequencies by two spaced relay stations and the propagation times indicated on three c-r tubes whose scales have a vernier relationship.

U. S. No. 2,497,513. G. R. Paine and W. C. Platt. Iss. 2/14/50. App. 6/10/48. Assign. General Precision Laboratory, Inc.

Radio Navigation System. A loran system in which the velocity of drift toward coincidence of pips may be manually controlled and having a coincidence-maintenance circuit which automatically locks the signals.

U. S. No. 2,498,732. E. O. Willoughby. Iss. 2/28/50. App. 8/11/44 and 8/11/45. Assign. International Standard Electric Corp.

Radio Navigation System. A blind landing system in which two overlapping radiation patterns are commutated, one being an a-m carrier at side-band frequency and the other an unmodulated carrier, the oscillating pattern being picked up by an f-m receiver.

U. S. No. 2,498,919. J. I. Heller. Iss. 2/28/50. App. 2/15/46. Assign. Panoramic Radio Corp.

Direction Indicating and Finding System. A radio compass using a loop antenna and a vertical antenna whose signals are combined into a cardioid direction pattern through two channels tuned to two transmitting stations and their difference pattern indicated on a c-r tube.

U. S. No. 2,499,228. C. L. Norden. Iss. 2/28/50. App. 9/25/45. Assign. The Norden Laboratories Corp.

Stabilization of Directional Devices. A system of controlling the azimuth of an axially-stabilized aircraft radar antenna so that a sudden transition may be made from a homing course to a collision Course.

316—RADIO RANGING

U. S. Re. No. 23,194. (Orig. No. 2,459,461). R. G. Shankweiler and D. Blitz. Iss. 1/31/50. App. 6/23/45, 1/18/49 and 10/15/49. Assign. Radio Corp. of America.

Frequency Modulation Distance Indicator. A frequency-modulated radio altimeter in which the period of frequency increase is much longer than the period of frequency decrease and the receiver produces a beat only during frequency increase of both transmitted and reflected signals.

U. S. No. 2,494,553. P. G. Hansel. Iss. 1/17/50. App. 10/16/45.

Direction Finding System. A radio direction finder using four antennas at the corners of a square with a reference antenna in the center connected to a phase shifter arranged to distort the goniometer signal to produce a symmetrically-split pattern on a c-r tube so that signal distortion can be detected.

U. S. No. 2,498,381. R. M. Smith. Iss. 2/21/50. App. 4/12/39. Assign. Radio Corp. of America.

Radio Echo Distance Measuring Device. A radio pulse echo system in which the receiver's sensitivity is gradually increased after the termination of the transmitted pulse by a varying potential obtained from the c-r sweep circuit.

U. S. No. 2,499,520. P. M. Modlowski and A. M. Skudre. Iss. 3/7/50. App. 1/31/47. Assign. Raytheon Manufacturing Co.

Distance Measuring Device. An echo distance-measuring apparatus in which the transmitted and received pulses are applied to a vacuum tube and a gas tube in series so that the transmitted pulse establishes conductivity to a condenser and the reflected pulse cuts off the current and the charge is indicated on a meter.

324—RECORDER

U. S. No. 2,493,519. R. W. Baltosser. Iss. 1/3/50. App. 12/29/48. Assign. Seismograph Service Corp.

Reproducing and Translating Apparatus. A control unit for a seismograph analyzer in which a number of traces on transparent film are scanned by photocells and having a vacuum-tube voltmeter and attenuators for adjusting the output of each channel.

U. S. No. 2,495,652. W. K. Coburn. Iss. 1/24/50. App. 3/30/46 and 6/5/46. Assign. Serdex, Inc.

Chronometric Recorder. A recorder for recording coded weather information from a radiosonde and in which the recorder drum runs slightly faster than the transmitter drum but is stopped at the end of each cycle of signals and restarted on receipt of a reference signal from the radiosonde and the recorder-drum speed manually corrected to maintain approximate synchronism.

U. S. No. 2,497,142. J. O'D. Shepherd. Iss. 2/14/50. App. 12/18/41.

Sound Recorder and Reproducer. A recording system using a transparent filament which is deformed by a transverse blade in the recording process and a light beam is passed transversely through the filament in the reproducing process.

U. S. No. 2,497,759. H. L. Cappleman, Jr. Iss. 2/14/50. App. 12/2/46.

Rain or Snow Gauge. A precipitation gauge in which the material is collected in a container floating in mercury and the displaced mercury actuates a piston with a ratchet on the recording arm.

U. S. No. 2,499,603. W. A. Mueller. Iss. 3/7/50. App. 10/23/45. Assign. Radio Corp. of America.

Rerecording Method and System. A sound recording system in which dialogue is recorded on one channel and music and sound effects on a second channel with the amplification of the second channel controlled by the signal level in the first channel.

U. S. No. 2,499,618. W. V. Wolfe. Iss. 3/7/50. App. 3/8/46. Assign. Radio Corp. of America.

Plural Track Sound Reproduction. A sound-on-film recording system using two unilateral variable-area tracks one of which carries voice and the other carries music and high-level sound effects.

U. S. No. 2,501,790. D. Silverman. Iss. 3/28/50. App. 4/27/44. Assign. Stanolind Oil and Gas Co.

Photoelectric Spark Recorder. A photoelectric galvanometer-recording system in which the light beam from the galvanometer is passed through a spiral scanner which has a synchronously-rotating switch to a series of small electrodes which mark the recording paper when activated, the photocell impulse being amplified and applied to the appropriate electrode by the switch.

U. S. No. 2,501,791. D. Silverman. Iss. 3/28/50. App. 8/10/44. Assign. Stanolind Oil and Gas Co.

Inkless Recorder. A multichannel galvanometer-recording system in which the galvanometer beams are scanned by an iconoscope tube and reproduced in a c-r tube whose screen has a mosaic whose elements lead to small electrodes which mark the recording paper when activated.

344—SEISMOGRAPH AMPLIFIER

U. S. No. 2,493,534. J. E. Hawkins. Iss. 1/3/50. App. 6/13/47. Assign. Seismograph Service Corp.

Testing Device for Seismic Signal Apparatus. A seismograph amplifier-testing system in which the original record is made in variable area form with a separate record of the avc action and the records subsequently reproduced in variable amplitude form through a standard amplifier without avc and through the amplifier to be tested with avc.

356—SEISMOGRAPH MIXING

U. S. No. 2,496,648. A. Wolf. Iss. 2/7/50. App. 6/24/43. Assign. Texaco Development Corp.

Seismic Exploration System for Determination of Strata Dips. A system of seismograph recording which is sensitive to direction and in which the geophone signals are recorded on sound tracks which are subsequently photo-electrically reproduced by combining two tracks in opposition with the weathering correction removed.

360—SEISMOGRAPH PROSPECTING

U. S. No. 2,499,605. A. McL. Nicolson. Iss. 3/7/50. App. 2/25/43.

Method and Apparatus for Detecting Waves. A seismograph prospecting system using a pair of detectors connected so as to indicate which one receives a shock first and isochronic lines determined by moving the pair of detectors over the area.

364—SEISMOGRAPH RECORDER

U. S. No. 2,494,370. K. D. Swartzel and C. L. Frederick. Iss. 1/10/50. App. 2/8/45. Assign. Curtiss-Wright Corp.

Multichannel Telemetering System with Identical Band-Pass Filters. A multichannel radio recording system using bridge-type transducers excited at different frequencies which are combined and transmitted over a single f-m radio channel and the received signal modulated with local oscillators, filtered by crystal band-pass filters and rectified and recorded.

368—SEISMOGRAPH TIMING

U. S. No. 2,496,392. A. F. Hasbrook. Iss. 2/7/50. App. 9/27/48. Assign. O. S. Petty.

Apparatus for Recording Time Intervals. A system for putting timing marks on a moving record and having a light source flashed by tuning-fork-controlled pulses with the pulses also feeding a frequency divider whose output is also impressed on the light source so as to produce a longer pulse to indicate larger time units.

U. S. No. 2,497,143. J. R. Shonnard. Iss. 2/14/50. App. 10/23/46. Assign. Times Facsimile Corp.

Tuning Fork. A temperature-compensated tuning fork made of two forks of different metals and of different lengths fastened together over a small area at the tip of the shorter tines.

372—SEISMOGRAPH VOLUME CONTROL

U. S. No. 2,495,390. E. J. Shimek. Iss. 1/24/50. App. 3/20/46. Assign. Socony-Vacuum Oil Co., Inc.

Seismograph Gain Control System. An avc system for a seismograph amplifier in which part of the output is rectified and used to control the cathode bias of two tubes in push pull with their plate circuits unbalanced, the avc control shifting the bias to restore the balance and decrease the amplification.

U. S. No. 2,495,809. G. K. Graham. Iss. 1/31/50. App. 9/6/45. Assign. Radio Corp. of America.

Signal Expansion or Compression. An avc system in which part of the signal is rectified and used to control the static position of the transducing element in the magnetic field so as to vary its sensitivity.

U. S. No. 2,497,835. G. B. Loper. Iss. 2/14/50. App. 12/20/46. Assign. Socony-Vacuum Oil Co., Inc.

Variable Gain Voltage Amplifier. An avc system for seismograph amplifiers in which the amplification is changed by changing the suppressor voltage of one of the tubes whose load current is kept balanced by an auxiliary tube whose grid potential is simultaneously changed.

U. S. No. 2,501,327. L. H. Good. Iss. 3/21/50. App. 12/6/46. Assign. Radio Corp. of America.

Noise Operated Automatic Volume Control. An avc system in which the amplification is controlled by picking up the background noise and generating from it a logarithmic d-c bias voltage which is applied to a variable-gain amplifier.

376—SEISMOMETER

U. S. No. 2,501,558. F. J. Williams. Iss. 3/21/50. App. 3/7/49. Assign. Geophysical Service, Inc.

Coupling Means for Seismometers. A geophone having its coil coupled to a transformer core which extends outside the geophone case and is coupled to a loop taped into the cable conductor by a removable magnetic pin or by a mating magnetic core piece on the cable.

380—SEISMOMETER TESTING

U. S. No. 2,496,298. G. Mackas. Iss. 2/7/50. App. 2/5/46. Assign. U. S. A.

Shock Testing Apparatus. A device for imparting known acceleration to a test table in which the table is dropped onto a cantilever spring of known frequency and deflection and whose length is adjustable.

U. S. No. 2,498,844. G. R. Sears, R. D. Rae and J. A. Van den Akker. Iss. 2/28/50. App. 8/16/47. Assign. The Institute of Paper Chemistry.

Impact and Acceleration Testing. An impact-testing table which is suspended as a pendulum and released from a displaced position to strike a stop.

392—SIDE WALL SAMPLER

U. S. No. 2,494,932. C. O. Denning and J. R. Yancy. Iss. 1/17/50. App. 4/16/48. Assign. A-1 Bit & Tool Co., Inc.

Sidewall Coring Tool. A device for taking side-wall cores and having a whipstock with a longitudinal rib which grips the side of the hole and a core barrel on a sectional driving stem which is deflected into the wall of the hole.

U. S. No. 2,495,439. N. B. Brimble. Iss. 1/24/50. App. 8/8/45.

Side Wall Sample Taker. A side wall sampling tool having a whipstock with slips which grip the sides of the hole and a core drill on a universal connection which is deflected to drill into the side wall.

U. S. No. 2,500,125. T. A. Huber. Iss. 3/7/50. App. 6/25/45. Assign. Standard Oil Development Co.

Sidewall Coring Device. A sidewall-coring device having a spring which may be released by a go-devil to force pivoted coring tubes against an annular ring which guides them into the formation, with further action of the go-devil releasing the annular ring to permit the tubes to be retracted for withdrawal from the hole.

U. S. No. 2,500,252. L. B. Ice. Iss. 3/14/50. App. 1/31/47.

Side Wall Coring Device. A sidewall-coring device having an end piece with a hydraulically-operated dog which grips the side of the hole and a rotatable stem which turns a small-diameter core drill which is deflected by a guide in the end piece and may be removed by a wire-line overshot.

396—SOIL ANALYSIS

U. S. No. 2,500,213. N. P. Stevens. Iss. 3/14/50. App. 3/28/45. Assign. Socony-Vacuum Oil Co., Inc.

Geochemical Exploration Method by Infrared Analysis of Soil Extract Solutions. A method of soil-analysis prospecting in which soil samples are extracted with a hydrocarbon solvent and the hydrocarbon content determined by an infra-red absorption analysis.

420—SPECTROPHOTOMETER

U. S. No. 2,494,440. H. E. Haynes. Iss. 1/10/50. App. 5/31/46. Assign. Radio Corp. of America.

Spectrophotometer Apparatus Having a Rotating Slotted Wheel to Decrease Light Intensity. A spectrophotometer in which linearity at low intensities is obtained by interposing in the standard beam a rotating disc with narrow radial slots to reduce the amount of light by a known amount.

428—STRAIN GAUGE

U. S. No. 2,493,029. W. Ramberg. Iss. 1/3/50. App. 9/25/45.

Electric Dynamometer. An axial dynamometer having thick-walled tubular ends with a thin inwardly-extending annular corrugation on which is wound a filament-type strain gauge.

U. S. No. 2,493,758. E. J. Friedrich. Iss. 1/10/50. App. 10/22/45.

Torque Measuring Device. A device for measuring torque of a motor and having a metallic disc fastened to the shaft and a pendulous magnet which is deflected by eddy currents in the disc.

U. S. No. 2,494,370. K. D. Swartzel and C. L. Frederick. Iss. 1/10/50. App. 2/8/45. Assign. Curtiss-Wright Corp.

Multichannel Telemetering System with Identical Band Pass Filters. A multichannel radio recording system using bridge-type transducers excited at different frequencies which are combined and transmitted over a single f-m radio channel and the received signal modulated with local oscillators, filtered by crystal band-pass filters and rectified and recorded.

U. S. No. 2,496,632. B. J. Lazan. Iss. 2/7/50. App. 12/14/44. Assign. The Baldwin Locomotive Works.

Vibration Testing Apparatus. A continuous-wave testing apparatus using a motor-driven mechanical vibrator whose speed is controlled from the pickup amplifier so as to maintain a predetermined amplitude of vibration in the test structure.

U. S. No. 2,498,282. B. F. Langer. Iss. 2/21/50. App. 9/15/42 and 5/15/46. Assign. Westinghouse Electric Corp.

Torque Measuring Device for Shafts. A strain gauge for a rotating shaft having a coil around the shaft with an annular pole-piece shell and spaced fingers on the shaft which vary the air gap with change in torque in the shaft.

U. S. No. 2,498,844. G. R. Sears, R. D. Rae and J. A. Van den Akker. Iss. 2/28/50. App. 8/16/47. Assign. The Institute of Paper Chemistry.

Impact and Acceleration Testing. An impact-testing table which is suspended as a pendulum and released from a displaced position to strike a stop.

U. S. No. 2,499,033. J. M. Oberholtzer. Iss. 2/28/50. App. 5/26/47. Assign. North American Aviation, Inc.

Impact Dynamometer. An impact-measuring table which is suspended on horizontal cantilever beams at its four corners with filament-type electric strain gauges on the beams connected in a bridge circuit.

U. S. No. 2,499,665. R. Mestas. Iss. 3/7/50. App. 8/3/40 and 2/16/46. Assign. Kobe, Inc.

Electric Gauge Head. A variable-air-gap reluctance-bridge-type motion detector having an E-shaped fixed core with long end legs between which the armature moves.

U. S. No. 2,500,764. W. D. Macgeorge. Iss. 3/14/50. App. 3/21/45. Assign. The Baldwin Locomotive Works.

Fatigue Testing Apparatus. A fatigue-testing machine having a pivoted bar with a clamp for the specimen on one side of the pivot and a counter-balancing spring, rubber damper and electro-magnetic driver on the other side, the driving coils being in an oscillating circuit controlled by a filament-type strain gauge on the specimen.

U. S. No. 2,500,836. R. P. Lathrop. Iss. 3/14/50. App. 5/3/45. Assign. The Baldwin Locomotive Works.

Extensometer. A mechanical extensometer having gauge blocks whose relative axial movement is measured by a mechanical multiplying lever system which averages torsional effects.

436—SUBMARINE SIGNALING

U. S. No. 2,495,730. J. M. Ide. Iss. 1/31/50. App. 11/12/43.

Underwater Sound Generator. A low-frequency underwater sound generator having a flexible diaphragm whose edge is mounted on a supporting diaphragm to which is connected a motor-driven unbalanced rotor.

U. S. No. 2,496,060. C. W. Mell, E. C. Ballentine and J. V. O'Neill. Iss. 1/31/50. App. 8/29/44. Assign. Radio Corp. of America.

Submarine Signaling Device Covered with Waterproof Vibration Damping Shield. A hydrophone whose case and diaphragm are covered with a layer of neoprene with the back of the case covered with a layer of cork or a mixture of ground cork and neoprene.

U. S. No. 2,497,901. E. E. Mott. Iss. 2/21/50. App. 8/18/44 and 9/18/45. Assign. Bell Telephone Laboratories, Inc.

Magnetostrictive Transmitter. A supersonic hydrophone having an array of annular magnetostrictive elements which are laterally sonically insulated and whose inner surface is in contact with the medium.

464—THERMOSTAT CONTROL

U. S. No. 2,498,212. W. D. Laverell, T. M. Walton and F. H. Mumberg. Iss. 2/21/50. App. 1/27/47. Assign. Precision Thermometer & Instrument Co.

Thermoregulator. A sealed mercury thermostat in which the contact is adjusted by rotating a screw by an external magnet.

484—TRANSDUCER

U. S. No. 2,493,466. W. F. Smith. Iss. 1/3/50. App. 7/10/46. Assign. Radio Corp. of America.

Phonograph System and Stylus Therefor. A phonograph needle made of a non-conductor and having a conducting coating which forms a circuit around the point and is connected in the amplifier-input circuit so that reproduction is automatically cut off when the needle gets dull.

U. S. No. 2,493,745. K. B. Blodgett and V. J. Schaefer. Iss. 1/10/50. App. 11/5/47. Assign. General Electric Co.

Method of Making Electrical Indicators of Mechanical Expansion. A method of forming a strain-sensitive electrically-conducting coating by painting the member to be coated with an adhesive and bringing it into contact with conducting particles floating on the surface of a liquid.

U. S. No. 2,493,819. W. R. Harry. Iss. 1/10/50. App. 11/25/47. Assign. Bell Telephone Laboratories, Inc.

Stabilized Feed-back Condenser Microphone. A condenser microphone in which movement of the diaphragm modulates a high-frequency carrier which is demodulated and fed to the other plate of the microphone condenser.

U. S. No. 2,494,390. A. Johnson. Iss. 1/10/50. App. 7/7/47.

Electrical Pickup. A variable air-gap reluctance-type pickup for a woodwind musical instrument in which the armature is vibrated through a connection to the reed.

U. S. No. 2,494,438. E. A. Gilbert. Iss. 1/10/50. App. 5/31/46. Assign. Radio Frequency Laboratories, Inc.

Phonograph Pickup. A phonograph pickup in which the stylus vibrates a vane edgewise between coils to vary the tuning of an oscillator and with the coupling between the stylus and the vane interrupted by a mounting which prevents transmission of needle-scratch vibrations.

U. S. No. 2,494,570. G. R. Mezger. Iss. 1/17/50. App. 1/22/46.

Electricel Transducer. An engine-pressure indicator having a hollow metal cylinder with a flexible diaphragm at one end and connected as a resonant cavity in an ultra-high-frequency circuit.

U. S. No. 2,494,579. J. R. Pimlott and S. E. Dawson. Iss. 1/17/50. App. 8/19/48.

Differential Transformer Pickup Unit. A variable air-gap reluctance-bridge-type transducer having a longitudinally-moving armature with air-gaps at each end and surrounded by a cylindrical shell with end plates and pole pieces and an annular middle plate separating two pairs of coils inside the shell.

U. S. No. 2,494,918. W. K. Volkers. Iss. 1/17/50. App. 9/17/46. Assign. Volkers & Schaffer, Inc.

Inductively Energized Electrodynamic Loud-Speaker. A loud speaker in which the voice coil is rigidly mounted in the air-gap and the diaphragm carries two concentric rings between the coil and the magnet pole pieces.

U. S. No. 2,496,484. F. Massa. Iss. 2/7/50. App. 4/17/46.

Magnetostrictive Phonograph Pickup. A phonograph pickup in which the stylus flexes a bimetallic magnetostrictive vane with stationary polarizing magnet and coil.

U. S. No. 2,497,108. A. L. W. Williams. Iss. 2/14/50. App. 6/12/48. Assign. The Brush Development Co.

Electromechanical Transducer. A piezoelectric transducer using barium titanate in the form of a spiral or a series of bars whose elongations are added.

U. S. No. 2,497,172. C. H. Kean. Iss. 2/14/50. App. 9/27/47. Assign. Standard Oil Development Co.

Means for Mounting Elongated Magnetostrictive Elements. A mounting for an oscillating magnetostrictive bar in which the bar is held at its midpoint by pins from a tapered ring which fits into a similarly-tapered ring in the housing.

U. S. No. 2,497,680. F. Massa. Iss. 2/14/50. App. 3/26/42 and 1/19/44. Assign. The Brush Development Co.

Piezoelectric Crystal Unit. A piezoelectric hydrophone having an oil-filled case and crystal units with four active faces, two of the faces being covered with a layer of cork to decouple them from the oil.

U. S. No. 2,497,770. R. L. Hanson. Iss. 2/14/50. App. 12/29/48. Assign. Bell Telephone Laboratories, Inc.

Transistor-Microphone. A microphone in which the diaphragm changes the pressure of carbon granules against the sides of a transistor so that an amplified response is obtained

U. S. No. 2,497,901. E. E. Mott. Iss. 2/21/50. App. 8/18/44 and 9/18/45. Assign. Bell Telephone Laboratories, Inc.

Magnetostrictive Transmitter. A supersonic hydrophone having an array of annular magnetostrictive elements which are laterally sonically insulated and whose inner surface is in contact with the medium.

U. S. No. 2,498,210. C. E. Kilgour. Iss. 2/21/50. App. 11/2/48. Assign. Avco Manufacturing Corp.

Piezoelectric Phonograph Pickup Device. A piezoelectric phonograph pickup having a torsion crystal with one end fastened to the case and with its free end connected to a cantilever bar whose other end is fastened to the case, the stylus engaging the middle of the cantilever bar.

U. S. No. 2,498,671. M. L. Gayford. Iss. 2/28/50. App. 1/26/45 and 1/5/46. Assign. Internationa Standard Electric Corp.

Sound Reproducer or Recorder Head. A balanced armature type phonograph pickup in which the stylus vibrates a magnetic vane which is attached to the head by non-magnetic lugs.

U. S. No. 2,498,737. C. R. Holden. Iss. 2/28/50. App. 6/7/46. Assign. W. H. T. Holden.

Electromechanical Transducer. A piezoelectric acoustic vibrator for supersonic treatment of liquids and having a stack of quartz plates, the end one of which forms a partition, so that the liquid to be treated may be circulated against one end of the vibrating stack and cooling oil circulated around the stack.

U. S. No. 2,498,825. C. L. Richards. Iss. 2/28/50. App. 9/15/43 and 1/19/45. Assign. The Hartford National Bank & Trust Co.

Moving Coil Transducer and Enclosure. A permanent-magnet moving-coil-type loudspeaker in which the magnet is sealed against dust and moisture by a front diaphragm which carries the coil and by a sealing diaphragm across the back.

U. S. No. 2,499,110. S. R. Rich. Iss. 2/28/50. App. 5/15/46. Assign. Tobe Deutschmann.

Magnetostrictive Phonograph Pickup Unit. A phonograph pickup in which the stylus is attached at the midpcint of a magnetostrictive wire wound with small coils and held between the poles of a permanent magnet.

U. S. No. 2,500,541. E. H. Greibach. Iss. 3/14/50. App. 7/18/45.

Inertia-Type Electromechanical Sound Transducing Device. A throat microphone or bone-conduction receiver having an armature mounted on a thin diaphragm and a magnet structure mounted on a thicker diaphragm with S-shaped slots.

U. S. No. 2,500,561. L. D. Norton. Iss. 3/14/50. App. 9/30/48. Assign. Dictaphone Corp.

Phonograph Pickup Having Elastic Drive Member. A piezoelectric phonograph pickup in which the stylus vibrates a pivoted rocker arm to which the crystal is connected by a link made of two wire hooks embedded in rubber.

U. S. No. 2,501,233. W. J. O'Brien. Iss. 3/21/50. App. 3/14/45 and 3/19/46. Assign. The Decca Record Co. Ltd.

Phonograph Pickup Having Permanent Magnet Armature. A phonograph pickup having two humbucking stationary coils with the stylus vibrating a small permanent magnet so that the emfs induced in the coils will add.

U. S. No. 2,501,560. M. Blau. Iss. 3/21/50. App. 4/26/47. Assign. Canadian Radium & Uranium Corp.

Apparatus for Indicating and Measuring Small Movements. A transducer having a moving screen with progressively-graduated amounts of a radioactive material and a stationary radioactivity detector whose output is indicated.

U. S. No. 2,502,132. P. C. Efromson and R. C. Lewis. Iss. 3/28/50. App. 1/5/49.

Pickup For Use In Acceleration Indicating, Measuring, and Recording Apparatus. A vacuum-tube pickup in which one electrode of the tube has an actuating arm extending through a flexible portion of the envelope and has an inertia mass mounted on the arm.

492—VIBROMETER

U. S. No. 2,494,109. C. M. Wolfe. Iss. 1/10/50. App. 4/29/49. Assign. Aerojet Engineering Corp.

Metallic Film Electrical Pickup. An accelerometer having a mass on a cantilever arm whose sides are in electrical contact with a metallic film on adjacent curved posts so that bending of the arm against the posts changes the length and resistance of film in a push-pull circuit.

U. S. No. 2,496,295. R. M. Langer. Iss. 2/7/50. App. 12/10/45.

Vibration Spectrometer. A mechanical resonance vibrometer having a number of cylindrical reeds whose lengths may be simultaneously adjusted by a sliding block.

496—VISCOSIMETER

U. S. No. 2,497,919. R. N. Weltmann. Iss. 2/21/50. App. 11/1/45. Assign. Interchemical Corp.

Viscometer Recorder. A rotating cup viscosimeter in which the inner cup is rotated against a spring and its deflection imparted to an electrode which moves across a moving recording paper and a record made by a spark to the electrode from a backing bar.

516—WELL SIGNALING

U. S. No. 2,501,953. P. W. Martin. Iss. 3/28/50. App. 5/22/45.

Electrical Well Logging System. A well-logging system using a low frequency for logging and a high frequency for recording, the high frequency being modulated by the positive half-cycles of the low frequency for one logging parameter and by the negative half-cycles of the low frequency for a second logging parameter, with the two parameters' signals separated by rectifiers at the surface.

INDEX OF PATENTS ABSTRACTED IN GEOPHYSICS, 1949

O. F. RITZMANN*

INTRODUCTION

This index covers the patent abstracts published in the following four issues of GEOPHYSICS—July 1949, October 1949, January 1950, and April 1950—the patents having been issued by the U. S. Patent Office during the calendar year, 1949. For previous indices reference may be had to the Geophysical Patent Index of the S.E.G. Cumulative Index (1948), and to Index of Patents Abstracted in GEOPHYSICS, 1947–1948, GEOPHYSICS, Vol. XIV, No. 3, pp. 395 to 434, July 1949.

The form of this index parallels that of previous ones. The complete subject classification and cross reference list is given. This index covers 714 published abstracts of patents, a number 50% larger than that of any previous year. It may be noted that while the number of patents in the broad classifications has declined, the number of patents concerning details of apparatus used and of interest in geophysical operations has substantially increased. The manner in which the subject classification is broken down accentuates this trend.

The abstracts are not to be construed in any sense as an interpretation of the patents.

The author of the abstracts and of the index appreciates permission of the officials of the Gulf Oil Corporation to undertake this abstracting and to use its secretarial staff in this connection, and acknowledges the assistance of Mrs. M. L. C. Ritzmann in checking the manuscripts and proofs.

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2,473,491	K. Posthumus	XIV, 4, 574
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2,492,446	XV,	2,	290
2,492,459	XV,	2,	271
2,492,493	XV,	2,	272
2,492,794	XV,	2,	278, 290
Re. 23,090	XIV,	3,	381
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Re. 23,102	XIV,	4,	565
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REVIEWS

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REFLEXION ET REFRACTION DES ONDES SEISMIQUES PROGRESSIVES, BY L. CAGNIARD

Reflexion et Refraction des Ondes Seismiques Progressives, by L. Cagniard, Gauthier-Villars, Paris (1939).

This book treats a very important series of problems that arise when a point source of a seismic pulse is located near the plane interface joining two different semi-infinite, homogeneous, isotropic elastic media. Earlier treatments, very incompletely referred to in the present book, start with the treatment of sinusoidal waves and pass to the consideration of pulses via the Fourier integral synthesis. Cagniard employs the Laplace transform technique so useful in electrical circuit theory. His justification of this process is given in detail in his Chapter III, which is a chapter in pure mathematics. The time variable is transformed by the Laplace transformation. The process is entirely parallel with the analysis in terms of harmonic components of the pulse excepting that the Laplace transform theory is easier to handle without reference to embarrassing, but simple exceptions such as occur in connection with the Fourier transforms.

After a brief description of notations with the basic differential equations and interface conditions in Chapter I, the author passes on, in Chapter II, to a more detailed description of the source and the initial conditions. For most readers, probably Chapter II will appear too brief, as it is in this chapter that the physical problem is set. This reviewer has a strong feeling of confidence in the supposition that once a problem is *completely* stated in physical terms it can theoretically be solved and this solution is, if correctly carried out, unique. An advantage of Cagniard's treatment is that it appears to be set in such a form as to allow the direct application of Neumann's uniqueness theorem (Love, "Elasticity" p. 176). This would be a trivial statement, if treatments via the Fourier synthesis were also of this character, but they are not. The reason is that in the latter case we have to specify conditions that amount to making an arbitrary choice as to whether we wish to, in the case of the free surface, include Rayleigh waves or not (See P. S. Epstein, Proc. Nat. Acad. Sci., *33*, 195 (1947)). The problem is one that calls for greater completeness in the statement of the physical problem and this requirement for the steady state motion is discouragingly difficult; the Sommerfeld divergence condition which is sometimes used is certainly of doubtful validity. There is another difficulty, called to the reviewer's attention by Mr. S. Meiboom, which may be important in the steady state case, namely the more complete specification of stress at the source cavity boundary due to the secondary waves. Though such a specification, if left out, would leave the physical problem incompletely stated, it appears that Cagniard has taken care of this adequately (page 9).

In Chapter IV, the solutions are expressed in terms of integrals of the Bessel function $J_0(\lambda\rho)$, and the appropriate exponentials in z. The coefficients are determined and it is shown that the path of integration is entirely free of singularities and so no obvious ambiguity attends the process of evaluation of the integrals. As has been pointed out to the reviewer by Mr. H. Rainbow, Epstein's process cannot be applied in this case, as any path deformation which includes a negative real part for λ

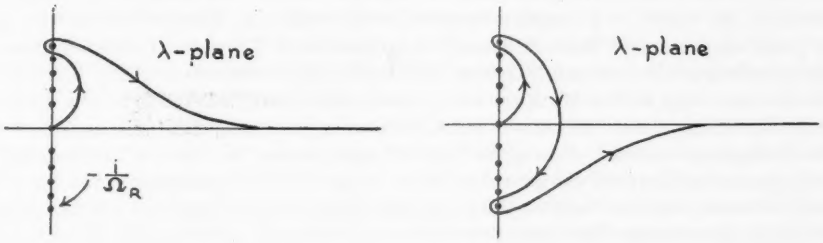
makes some of the integrals divergent at $z=\infty$ which can be ruled out on direct physical considerations. The conditions for the existence of a Stoneley wave are beautifully presented in a graph on page 50 showing the necessity of having the shear wave velocities very close together.

If the reader can follow the author's reasoning through the fourth chapter then he will be ready to follow what appears to the present reviewer to be a masterly chain of analysis from Chapter V (page 54) up to page 119 of Chapter VII, where a general recapitulation of results of the analysis is to be found. The details of this analysis appear to be correct to the present reviewer but there exist so many details that errors could have escaped detection. However all of the pulses Cagniard finds can be also found by an appeal to the physical considerations as illustrated in the reviewer's note (*Geophysics* IV, p. 238). This adds to the reviewer's confidence in Cagniard's analysis. Of course Cagniard's results are quantitative and detailed whereas the reviewer's are not.

Chapter VIII is a discussion of the static deformation of the elastic system. This discussion has many interesting applications most of which lie outside the field of exploration geophysics.

Chapter IX discusses the "steady state" sinusoidal case in so far as that case can be described in terms of a source which starts oscillating at $t=0$ and for which the subsequent state of the system can be examined at a much later, but finite, time.

Chapters X, XI, XII, and XIII (88 pages) refer to the problem where the second medium is empty, or practically empty; a case of major importance for all seismologists. Several details of



Chapter X will be of particular interest to seismologists, namely the distribution of the kinematic discontinuities for the reflected compressional and shear waves represented in Figures 43 and 45 respectively. Chapter XI is a discussion of Rayleigh waves. The "tailing" and "oscillatory character" are accounted for as much as this can be done neglecting the important effects of stratification.

Another surface wave is discussed in Chapter XII which travels with the velocity of the shear wave and which exhibits a "direct" elliptical motion in contrast with the "retrograde" motion of the Rayleigh wave. The principal period of this latter surface wave is about double that of the Rayleigh wave. The amplitude of the Rayleigh wave becomes predominant at large distances; e.g., at nine times the focal depth it is about twenty times greater than the amplitude of the other surface wave.

Chapter XIII refers to a phenomenon referred to earlier in the book (pp. 158–161) which this reviewer fails to understand fully. The reflected shear wave, for a compressional point source, remains zero on a vertical axis through the source. Then as one leaves this axis the intensity of the shear wave increases and then decreases. After a long time the central part of this wave becomes approximately a spherical cap. This spherical cap joins continuously to a conical part of the wave front. The lateral gradient of amplitudes away from the junction circle of the cap and cone appears such that at very large times this junction circle becomes a relative singularity. Such a phenomenon is discussed in Chapter XIII. The final chapter (XIV) gives a discussion of the effect of the atmosphere and oceans on Rayleigh waves and the behavior of some of the waves mentioned earlier at great distances.

This book can be highly recommended to readers with a good background in the theory of functions of a complex variable. The steps in the analysis are clearly presented. The printing is excellent and remarkably free from errors. This reviewer suggests that a few critical cases be worked out

numerically and that these be checked by model studies. A closer tie between the theory and controlled observations should go far to justify more extensive numerical computations based on Cagniard's results.

C. Hewitt Dix
California Institute of Technology

EARTH WAVES, BY L. DON LEET

Earth Waves, by L. Don Leet, Harvard Monographs in Applied Science, No. 2, 122 pp., 1950, Harvard University Press, John Wiley and Sons Inc.

Earth Waves is the second of the Harvard Monographs in Applied Science. It is a beautifully printed little book of one hundred and twenty-two pages. Being written by a member of the Editorial Committee, this book is probably representative of future Monographs of the Harvard Series. The author has strictly limited the contents to a few selected topics in the field of earth waves. It is written for a reader with a fair technical background and a strong curiosity for samples of knowledge outside his own specialty. It is not intended for a specialist in seismology. The author has written for such an audience fairly consistently after the first twenty-eight pages, which are out of keeping with the main course of the Monograph.

The common Foreword for all the Monographs in this series explains that the Monographs are designed to provide a medium for publishing the results of fundamental research by Harvard staff members with due regard to a critical orientation of the work in its technical background. About twenty pages are devoted to Harvard research in a broad sense. The research topics discussed are seismographs designed by Leet and Blumberg, the identification on records of quarry blasts and the 1945 atomic bomb blast in New Mexico of two types of surface waves believed to be new, travel time curves for New England and the study of microseisms using three component seismographs.

The background material, of some one hundred pages, covers the theory of seismographs, the observed types of earth waves, the geometric theory of seismic wave transmission, and the work of St. Louis University and the Navy on the use of microseisms for predicting and locating overwater meteorological disturbances. The chapter on the types of observed earth waves is the high point of the book, whether or not one is convinced by the evidence presented to prove the existence of two new types of surface waves. Leet's "Hydrodynamic" wave was discovered theoretically by Cagniard and called by him the "second surface wave" in his "Reflexion et Refraction des Ondes Seismiques Progressives"* in 1939. The chapter on microseisms repeats the author's warning against the over-optimism of some of the microseismic hurricane hunters. He perhaps over emphasizes the weaknesses of the tri-partite station method, but, in general, his criticism should serve a useful purpose.

The common Foreword for this series of Monographs explains that they are designed not primarily for the first publication of research results, but for providing a wider audience than reached by individual professional journals. Most of the material in this Monograph was compiled from the previous publications of the author, particularly, his "Practical Seismology and Seismic Prospecting" published in 1938. The sections on Rayleigh and Love waves, for example, are reproduced practically verbatim.

W. M. Rust, Jr.
Humble Oil & Refining Co.

SCIENTIFIC AUTOBIOGRAPHY, BY MAX PLANCK

Scientific Autobiography, by Max Planck. Translated by Frank Gaynor, Philosophical Library (1949).

Perhaps the title of this small book of essays is misleading. If it prevents any scientifically or philosophically inclined person from reading the book, it will be considered an unfortunate title.

* Reviewed on page 546 of this issue.

Actually, four of these five essays present the carefully analyzed thoughts of one of our century's greatest minds as it considers the relationships between science and philosophy. Max Planck, the author, gained his immortality through the introduction of the quantum concept and gave his name to the fundamental physical constant associated with it. The introduction of this concept is known to have troubled Planck before, during, and after the first period of publication. His was a conservative mind which brought forth such radical ideas only with great reluctance. But, if the reader hopes to find this story in the autobiographical chapter of this volume, he will be disappointed. His disappointment will be short-lived when he finds the same type of analysis together with the same simplicity in the discussion of four important problems which affect the life of every scientist. As for the story which one might hope for in the autobiography, it must wait for another volume, because the recollections here are dimmed by the haze of nearly fifty years.

Some readers will agree with the general theme of Planck's essay on religion and natural science, while others will feel that he has only written an introduction to a much greater piece of work. Regardless of that, this essay must be accepted as a simple statement of a complex problem together with some of the author's personal opinions. While he has not gotten to the heart of the philosophical problem involved, his introduction should serve to start the reader toward that goal. It is when Planck discusses causality, or the meaning of exact science that the reader receives a synthesis of the life of this man. These are the types of problems with which he spent much of the last forty years of his life and in these essays he has summarized much of this thought in a clear, concise manner; just as he always insisted his writings in theoretical physics must be.

The fifth essay in this book is entitled "Phantom Problems in Science" and in it the author presents an interesting form of analysis which the reader can apply to a multitude of problems. The idea is quite simple, but like most simple ideas, there seems to be no end to the application that can be made of them. Planck merely suggests that before debating the pros and cons of an issue, before worrying about a particular problem, and especially before starting a scientific experiment, one should ask himself in a thorough fashion whether the question posed has a real or only an illusory answer. If it is illusory, it generally means that the question should not be asked or that it should be asked in other terms. His illustrations of this method are well chosen to indicate exactly the type of problems and situations to which this all applies.

W. J. Yost
Magnolia Petroleum Co.

EXPLORATION GEOPHYSICS, 2ND EDITION, BY J. J. JAKOSKY

Exploration Geophysics, 2nd Edition, by J. J. Jakosky, Trija Publishing Company, Los Angeles, California, 1950. 1195 pp. $12.50.

Dr. Jakosky's book was first published in 1940, and a review of the first edition, by Dr. E. A. Eckhardt, was published in *"Geophysics,"* Vol. VI, No. 1, January, 1941. The present, second, edition incorporates a substantial amount of new material and considerable revision of the text of the older edition.

It is impossible to characterize the volume briefly, except to say that it is a most comprehensive work, covering all phases of geophysical exploration. It is not primarily a textbook, an encyclopedia, a handbook, nor yet a reference book; still it has some features of each. For this reason, it is a difficult book to review.

In the preface to his first edition Dr. Jakosky listed some thirty well qualified individuals who assisted him as critics and collaborators, and the second edition lists a considerable number of other advisors, some of whom supplied portions of the text. The frequent, and sometimes disconcerting, changes in style and manner of presentation, observed throughout the book, are perhaps a result of this collaboration.

The arrangement of the material of the present edition follows closely that of the first. It retains one excellent feature of the first edition, namely a list of pertinent patents at the end of each chapter. It is improved by the addition of many more references to available literature.

A brief introductory chapter gives an historical account of the various methods of geophysical exploration and is followed by a chapter entitled "Geologic and Economic Background" specifying the type of exploration problems amenable to geophysical methods.

A chapter of 186 pages is devoted to magnetic methods. While quite complete, it is poorly organized. Perhaps the most useful portion of this chapter is that concerned with the Schmidt type magnetic balance. It is sufficiently precise and detailed to serve as a manual in training operators of field instruments. The discussion of the magnetic properties of rocks and minerals, is satisfactory, except that it fails to consider the influence of the permanent magnetic moments of rocks on results of magnetic exploration. Only a few pages are devoted to a discussion of the application of magnetic methods to exploration problems and these are rather unsatisfactory. The final portion of the chapter is a concise and well written account of the airborne magnetometer.

The chapter on gravitational methods, which was perhaps the weakest section of the first edition, has been revised and improved but still leaves much to be desired. Considerable space is devoted to relative and absolute gravity measurements by means of the pendulum, a method now obsolete in prospecting. An even longer section is devoted to a labored presentation of torsion balance theory which is more confusing than helpful; and many pages are devoted to a description of the construction, testing, and operation of the torsion balance. Because of the unimportance of this instrument in present day exploration much of this material might better have been omitted. On the other hand, the second portion of the chapter, dealing with the use of the gravity meter, can be recommended to anyone who has to deal with gravity data. Field procedures are discussed, necessary corrections to observed data are dealt with in a satisfactory manner, and a number of well chosen examples of observed gravity anomalies and their interpretation are discussed.

Two chapters, totalling 202 pages, are devoted to electrical methods. Those geophysicists interested in petroleum exploration will probably find little of interest here, although a brief account is given of the application of electrical methods of structural mapping in the Permian Basin of New Mexico and West Texas. Those interested in the use of electrical methods in locating ore bodies and placer deposits will find the chapter interesting and valuable. It reflects the very considerable experience of the author in this field.

The chapter on seismic methods covers 300 pages. It contains much valuable material but is poorly organized. The emphasis is on the mechanics of the field work associated with seismic surveying and the reduction of the data obtained. The usual theory of reflection and refraction shooting is presented, and computing methods are discussed. The chapter is profusely illustrated with pictures of instruments and field equipment. A few typical field records are shown. Those readers primarily interested in the interpretation and application of seismic surveys may be disappointed in the author's treatment but geophysical field personnel will find it quite valuable. The new material added in this edition includes a brief discussion of off-shore water shooting; the use of air shots in reflection shooting; and also a very interesting section on the application of seismic methods to problems of civil engineering.

A chapter on bore hole investigations, has been drastically revised and much expanded. It is now an outstanding section of the book. It deals primarily with electrical and radioactivity logging of wells; although other subjects are not neglected. That portion dealing with electrical well logging may well be considered required reading for anyone seriously interested in the interpretation of electrical well logs. In the discussion of the natural potentials observed in bore holes, no reference is made to the work of Rust and Mounce, and that of Wyllie. This omission is unfortunate but not important to the discussion. Some twenty pages are devoted to an account of gamma-ray and neutron well logging. The treatment is clear, concise, and quite adequate.

Another excellent feature of the new edition is an added chapter on radioactivity, contributed by the Laboratory for Nuclear Science and Engineering, Department of Geology, Massachusetts Institute of Technology. It includes a discussion of the phenomena of radioactivity, sufficient for the needs of the geophysicist; together with a good presentation of methods and apparatus used in measurements of radioactivity. The practical application of these methods to exploration for radioactive ore

bodies is discussed. In addition, this chapter gives much information of value to those interested in radioactivity well logging.

As in the first edition, a brief chapter is devoted to chemical methods and another to thermal methods. Another chapter, on production problems is possibly misnamed. It deals almost exclusively with the determination of fluid levels in wells by sonic echo methods. A final chapter considers miscellaneous matters including insurance, trespass practice, land tenure, patents.

Exploration Geophysics has a place in the library of the practicing geophysicist. Although not suitable for use as a textbook, it should be useful as collateral reading in courses in geophysics provided assignments are judiciously made. It is not a book to be read without guidance by a beginner in the field.

W. T. Born
Geophysical Research Corporation

GEOCHEMISTRY, BY KALERVO RANKAMA AND TH. G. SAHAMA

Geochemistry by Kalervo Rankama and Th. G. Sahama. The University of Chicago Press, Chicago (1950). Pp. 912.

The authors, in the following quotation from the preface, have stated the essence and objectives of this book as well as if not better than could be done by almost any reviewer. "The purpose of this book is neither to serve as a textbook of geochemistry nor to give a complete account of all geochemical information. It is an attempt to survey the broad field of geochemistry and to account for the present state of geochemical knowledge and is mainly intended for the use of the geologist who has the necessary background in chemistry and of the chemist who possesses an adequate knowledge of the geological sciences." Consequently, the reader has synthesized for him much of the basic thoughts, ideas and data accumulated and presented in numerous books and articles by such leaders in the fields of geochemistry and petrology as Clarke, Goldschmitt, Niggli, Daly, Eskola, Bowen, and many others. In addition, the title of this book, *Geochemistry*, without further qualification, is another clue to the broad scope of its contents in that the geochemical characteristics of not only the lithosphere, hydrosphere and atmosphere are discussed in detail but a considerable amount of space is directed toward a discussion of the geochemical aspects of cosmochemistry. In this regard at least the reviewer was somewhat startled to find approximately 50 pages devoted to this subject and only 18 pages specifically assigned to the geochemistry of the oceans, including three pages on the biogeochemistry of the sea.

The chapter discussing the geochemistry of the biosphere should be of particular interest to geophysicists and geologists engaged in petroleum exploration because of the succinct and lucid exposition of the geochemical role of bacteria in the origin of petroleum both as a mechanism for transforming organic source material directly, as well as modifying the chemical environment in which these processes are conducted. The second part of the book constitutes an almost indispensable reference source for those interested in prospecting, or in just understanding, the chemical characteristics of the elements and compounds of economic value. The value of this compendium is greatly augmented by the presence of a most comprehensive bibliography of more than 700 items including many pertinent foreign references. A number of appendices of particular use to research specialists are presented, including a table in which the atomic and ionic radii of the elements are listed, as well as tables of gravimetric conversion factors for the elements and their geochemically important compounds.

Richard A. Geyer

APPLIED SEDIMENTATION, EDITED BY PARKER TRASK

Applied Sedimentation, edited by Parker Trask. Prepared under the direction of the Committee on Symposium on Sedimentation, Division of Geology and Geography, National Research Council, Washington, D. C. John Wiley and Sons, New York and London. 707 pp. (1950).

This volume is a collection of 35 articles, each by a separate author, on various aspects of sedimentation having practical application. The articles are rather arbitrarily grouped under seven head-

ings: 1) basic principles of sedimentation, 2) engineering problems involving strength of sediments, 3) applications of processes of sedimentation, 4) applications involving nature of constituents, 5) economic mineral deposits, 6) petroleum geology problems, and 7) military applications. Although each chapter is written by a specialist in the field it covers, the presentation is on an elementary level, designed for readers who have had little previous contact with the various topics. The editor, Dr. Trask, summarized the general principles of sedimentation in the opening chapter.

The book appears to be primarily for geologists and civil engineers. Several of the chapters, however, should be of interest to exploration geophysicists. These are 1) "Geophysical Problems in Applied Sedimentation" by Roland F. Beers, 2) "Geochemical Prospecting for Ores" by H. E. Hawkes, 3) "Subsurface Techniques" by Daniel A. Busch, and 4) "Applications of Sedimentation to Naval Problems" by R. Dana Russell.

Dr. Beers' chapter is a 20 page summary of the entire field of geophysics, from meteorology and other branches of "pure science" geophysics through prospecting methods to well logging. Applications to sedimentation are discussed only incidentally. Although the coverage of each topic in the text is necessarily most sketchy, there is a well selected bibliography with pertinent comments on each item to guide more intensive reading.

Dr. Hawkes' chapter, 22 pages long, gives some interesting applications of geochemistry to mineral exploration and summarizes the progress of the past 15 years in this type of prospecting. Biogeochemical prospecting is considered at some length. It appears that distinct correlation is observed in many areas between the occurrence of metals in ore deposits and of their concentration in the overlying soil and vegetation. Its utilization in prospecting, however, is still in its infancy.

The chapter on subsurface techniques by Busch, 19 pages long, is mainly concerned with well logging methods, coring, and subsurface mapping. Russell's chapter on naval applications considers underwater sound transmission studies, bottom sampling, underwater seismic exploration and underwater photography. Here again the text is very brief but the complete bibliography should facilitate further study of the subject.

This book and Pettijohn's recent *Sedimentary Rocks* should go far to remedy the long felt shortage of readable and up-to-date books on this important phase of geology.

MILTON B. DOBRIN

GROUND VIBRATIONS NEAR EXPLOSIONS, BY B. F. HOWELL, JR.

"Ground Vibrations near Explosions," by B. F. Howell, Jr. *Bull. Seis. Soc. Am.*, vol. 39, pp. 285–310 (1949).

This paper is a condensation of the author's Ph.D. thesis in geophysics at California Institute of Technology. The work it describes was conducted while he was on the staff of United Geophysical Company using seismic equipment lent by this organization. Since the research had the joint support of an earthquake observatory and an exploration firm, it is not surprising that it aimed to explore the probed borderline region between earthquake seismology and seismic prospecting. As pointed out in Howell's introduction, the exploration geophysicist is more interested in the velocities and paths of seismic waves than in their detailed character. He assumes that only compressional pulses are important to him and treats other kinds of wave motion as background to be removed by appropriate filters. Yet a thorough understanding of the various waves obtained from an explosion would in many cases facilitate interpretation of records, particularly in areas of difficult shooting. Surface waves are particularly troublesome in reflection work, but the nature of many types observed near explosions is very imperfectly understood.

Howell measured the three components of ground motion resulting from an explosion at fourteen locations with shot-detector distances ranging from about 285 to 11,500 feet. The low frequency limit of his geophones and recording system was 3.5 cps. In addition to the compressional waves, he recorded three types of surface waves, all previously noted in the literature. Two of the surface wave types had much the same characteristics as those reported by Leet from dynamite explosions and from the New Mexico atomic bomb. These waves, have been designated respectively as "coupled"

and "hydrodynamic," the former having mainly longitudinal motion and the latter the direct elliptical motion of surface water waves.

Of the three types of surface waves Howell reports, only the Rayleigh waves have been given theoretical explanation in the literature. The author has endeavored to deduce mechanisms for the transmission of the other two, but finds that none based on established types of wave motion explain the observations adequately. The principal difficulty, he concludes, lies in the fact that unconsolidated near-surface sediments do not have the properties which elastic theory predicates for solids. It is worthy of note that both Leet's and Howell's experiments were in areas where the uppermost material is sandy or alluvial. In such formations the significance of the usual elastic constants becomes uncertain and their measurement most difficult.

Although Howell's published records show conspicuous dispersion in the Rayleigh waves, he makes no effort to relate the dispersion characteristics to the properties of the surface layering, which, as Jeffreys and Sezawa have shown, is responsible for dispersion in this type of wave. A complete prediction of the Rayleigh wave dispersion in the presence of an unconsolidated layer would be a formidable mathematical task. It might have been instructive, however, if the author had worked up a curve of group velocity versus period for the Rayleigh waves on his records and compared it with Jeffrey's and Sezawa's theoretical curves for various assumed elastic properties of the surface.

The paper is clearly written and orderly in approach. The author makes a commendable effort to explain his observation on the basis of existing wave theory, but is hindered by the inadequacy of this theory for the media with which he worked. The problem of elastic wave transmission in unconsolidated near-surface materials is difficult but so important that one hopes it will be given more attention than heretofore by mathematical physicists.

MILTON B. DOBRIN

VELOCITY—ACCELERATION RESPONSE FROM A SEISMIC PICK-UP VIA CONTROLLED DAMPING, BY R. J. JEFFRIES

"Velocity—Acceleration Response from a Seismic Pick-up via Controlled Damping," by R. J. Jeffries, *The Review of Scientific Instruments*, vol. 21, no. 2, pp. 115–117 (1950).

This paper presents facts either well known to geophysicists or at least tacitly understood by them, but the manner of presentation, in the opinion of the reviewer, is novel. It therefore might be appropriate to discuss it in some detail. Ordinarily an electrical output proportional to the ground velocity is derived from the relative motion. It is pointed out, however, that other modes of operation are theoretically possible. If sinusoidal ground displacement is made the basis of investigation, it is an elementary observation that the amplitude of the associated ground velocity is proportional to the frequency, while the phase is shifted 90° ahead. In addition, the amplitude of the associated ground acceleration is proportional to the square of the frequency, while the phase is shifted 180° ahead. For a simple seismic system, the amplitude- and phase characteristics are plotted as two universal families of curves versus the frequency ratio (ω/ω_n) with ω_n = natural frequency of the system, and for various damping factors (δ) as parameters.

A qualitative study of both characteristics for the range $0 \leqq (\omega/\omega_n) < 1$ reveals that the relative motion as a function of frequency might approximate a square law relation for $0.5 < \delta < 1$, while the phase, not even approaching a constant 180° shift, nevertheless, increases linearly. The latter behavior, however, is of a non-distorting nature, the system only suffering time delay; see, for example, E. A. Guillemin, *Communication Networks*, volume 2, page 476, John Wiley and Sons, 1935. The seismometer, then operated with the above limitations, might perform as a device whose relative motion is proportional to ground acceleration.

A qualitative study of the same sets of characteristics for the same frequency range but for $\delta \gg 1$ reveals almost linear amplitude vs. frequency and almost constant 90° shift vs. frequency response. Thus the device should have a relative motion which is proportional to the ground velocity. These ideas are pursued quantitatively and final conclusions are drawn from a log-log plot; namely, for $\delta = 0.7$ almost perfect acceleration response and for $\delta = 30$ almost perfect velocity response obtains. It

is suggested that an electro-magnetic "drag-type" damping could achieve the damping change-over and that the loss of amplitude due to the high damping should not prove serious. The latter statement may, of course, be disputed by seismologists. The paper does not stress sufficiently in what manner the "near-perfect" response breaks down with frequency, nor does it mention that for $(\omega/\omega_n) \gg 1$ the device becomes a true displacement indicator for any damping.

A. J. HERMONT

THE SEISMOLOGICAL IMPLICATIONS OF AEOLOTROPY IN CONTINENTAL STRUCTURE, BY ROBERT STONELEY

"The Seismological Implications of Aeolotropy in Continental Structure," by Robert Stoneley, *Roy. Astron. Soc., Mon. Not., Geophys. Suppl.*, Vol. 5, pp. 343–353 (1949).

The author discusses the consequences of aeolotropy (anisotropy) in the propagation of elastic waves through the surface layers of the earth. Particular emphasis is on a surface layer with transverse elastic symmetry about a vertical axis. It is shown that the wave motion is not reducible to purely compressional and distortional waves as with an isotropic solid. As a consequence a point compressional source generates both *P* and *S* waves.

Of particular interest to exploration geophysicists is the result that depths determined by refraction shooting are in error if departures from isotropy exist and are not allowed for. Additional results show that *SH* and *SV* waves travel at different velocities. Rayleigh waves can exist, although in modified form. Love waves can exist as in isotropic media.

It is questionable whether sedimentary layers ordinarily encountered in seismic prospecting show significant departures from isotropy. On the other hand the precision needed to observe such departures can probably be obtained only by using seismic prospecting techniques.

FRANK PRESS
Columbia University

AIRBORNE EQUIPMENT FOR GEOMAGNETIC MEASUREMENTS, BY L. H. RUMBAUGH AND L. R. ALLDREDGE

"Airborne Equipment for Geomagnetic Measurements," by L. H. Rumbaugh and L. R. Alldredge, *Transactions, American Geophysical Union*, Vol. 30, No. 6, pp. 836–838 (1949).

The paper is concerned primarily with the instrumentation of the AN/ASQ-3A modification of the war-time submarine detection magnetic airborne detector (MAD), which was developed by the Naval Ordnance Laboratory with the cooperation of the Bell Telephone Laboratories and others.

The instrument discussed in this paper measures variations in the earth's total field by utilizing the second harmonic generated in a saturable reactor. This harmonic is also used for orientation. By comparison, the saturable reactor instruments developed by the Airborne Instruments Laboratory, the Gulf Research and Development Corporation,* and others, employ all of the harmonics, within the band width limitations of the amplifiers employed, in the form of "pips," both for measurement and orientation. The AN/ASQ-3A magnetometer compensates for errors due to mis-orientation of the measuring element by taking the sum of the squares of the orientation error signals and introducing the resultant into an ambient field nullification circuit.

In addition to the description of details of the operation of this instrument, there is discussion under the following section headings: Instrumentation for Geophysical Exploration with *MAD*, which includes desirable performance requirements, field procedures, and use of Shoran for positional control; Reduction of Data; Future Airborne Magnetometers, which discusses possibility of measuring the magnetic field *vector* in order to improve existing magnetic charts over the oceans; and a Summary.

The authors state that the contour maps obtained with this instrument are usually dependable

* Wyckoff, R. D., The Gulf Airborne Magnetometer. GEOPHYSICS, Vol. 13, pp. 182–208 (1948).

to $\leqq 2$ gammas. To anyone who has examined the "herring-bone" or "washboarding" in the earlier, unsmoothed maps issued by the U. S. Geological Survey, which are based on surveys with the AN /ASQ-3A, this statement appears to be somewhat optimistic.

JOSEPH A. SHARPE
Frost Geophysical Corporation

AN INVESTIGATION OF THE APPLICABILITY OF GRAVIMETRIC AND MAGNETOMETRIC METHODS OF GEOPHYSICAL PROSPECTING, BY M. J. S. INNES

An Investigation of the Applicability of Gravimetric and Magnetometric Methods of Geophysical Prospecting, by M. J. S. Innes, Publication of the Dominion Observatory, Ottawa, Canada, Vol. XI, No. 10.

This paper deals with gravimeter and vertical magnetometer tests over the East Sullivan sulphide ore body, near Val d'Or, Quebec. The ore bodies occur as three lenses of massive sulphides along the steeply dipping contact of porphyries intrusive into Pre-Cambrian andesites. The cover is water saturated glacial clay and gravel up to about 40 feet thick. The resulting gravity anomalies are about 0.8 milligal giving a density difference for the sulphides of 0.7 g/cm^3 and a density in situ of about 3.5 g/cm^3.

The writer shows that the variation of gravity with varying thickness of less dense overburden is negligible compared to the magnitude of the anomaly. It should be noted that the anomaly is large, the cover is shallow, and the depth changes may be gradual over this 1,500 foot square area so that some of the anticipated variation may have been absorbed in the graphically derived regional. Magnetic highs of 10,000 and 5,000 gamma were observed over the ore bodies.

ARTHUR A. BRANT

GEOLOGICAL EXPLANATION OF GEOPHYSICAL ANOMALIES NEAR CERRO DE PASCO, PERU, BY F. C. KRUGER AND W. C. LACY

"Geological Explanation of Geophysical Anomalies near Cerro de Pasco, Peru," by F. C. Kruger and W. C. Lacy, *Economic Geology*, Vol. 44 (September-October). Pp. 485–591 (1949).

This paper gives the results of self-potential and resistivity electrical surveys made in 1946 and 1947 over areas of gossan lying along the northwestern border of the Cerro de Pasco volcanic vent. The principal Cerro de Pasco gossan area and great pyrite ore body, hosts to copper-silver and lead-zinc ores, lie along the southeastern margin of this vent about one mile distant from the surveyed area.

In the surveyed area a positive self-potential anomaly, which trends in the general direction of the margin of the vent, centers some 200 feet to the east of the principal areas of exposed gossan. Though the authors state that this anomaly gave "recorded potentials of more than 700 millivolts," their anomaly map shows an actual closure of only 400 to 500 millivolts. A resistivity map shows equi-resistivity contours of "maximum resistivity to a depth of 30 feet." The electrode configuration used to obtain this resistivity pattern is not given. A highly resistant zone, with approximately the same trend and extent as the self-potential anomaly, has a high resistivity center lying about 100 feet west of the self-potential center.

Several diamond-drill holes to test these anomalies yielded only barren cores and sludges, with "only sparse sulphides." The holes and cross sections indicate that the anomalous area is underlain by the gossan which crops out to the west of the self-potential center and dips gently southeast, following the bedding of a limestone formation as a *manto* and pinching out at depth. The gossans in this area are presumably either sulphide masses oxidized in place, or precipitations from iron solutions derived by oxidation of "not-distant" sulphides. Samples from old workings show up to 4.4 per cent copper.

Hydrothermal alteration in the area has formed alunite-bearing rocks containing sulphuric acid and secondary quartz. Surface and in-hole rock samples were examined microscopically in thin section

and the percentages of quartz and alunite were estimated, plotted, and contoured on a map. In the diamond-drill cores, the percentage of alunite decreases with depth. On the surface, the zone of alunitization correlates strikingly well with the self-potential anomaly in both trend and extent, and the abundance of quartz parallels the zone of high resistivity. The *p*H determinations, which were made on the rock samples to test the quantities of sulphuric acid present, showed the alunite-bearing rocks to be strongly acid in all instances, and the carbonatized or unaltered rocks to be neutral or alkaline. The *p*H determinations, however, did not consistently vary inversely with the proportion of alunite in the rocks.

The authors interpret the high resistivity zone as caused primarily by the distribution of the Mitu formation, quartzite and quartz-pebble conglomerate, in the area and only subordinately by the secondary quartz that is associated with the alunite. Because only sparse sulphides were encountered by drilling beneath the anomalous area, the authors interpret the self-potential anomaly as caused by a concentration cell, formed by "the strong acid content of the alunite-rich rocks coupled with the neutral to alkaline nature of the enclosing rocks."

To the present reviewer's knowledge, this is the first published account in which an observed self-potential anomaly in a mining district is ascribed solely to a concentration cell. To permit a better evaluation of their concentration-cell explanation, it would have been helpful if the authors had given additional information concerning the actual amount and kind of sulphides and base metals encountered in the drilling, especially in the gossan zone beneath the anomaly. At the present stage of our knowledge, the possible electrochemical effect of even small amounts of sulphides should not be discounted, especially where they occur under the conditions, of high acidity or high permeability which may exist in gossan areas. Data would also have been desirable on the actual *p*H values obtained both at the surface and at depth, and on the ground-water conditions in the surveyed area. The authors make no comment as to why a positive self-potential center, rather than a negative center was observed.

KENNETH L. COOK*

GEOLOGICAL AND GEOPHYSICAL SURVEY OF SOUTHEASTERN NETHERLANDS. EDITED BY L. U. DE SITTER

Eindverslag van het Geophysische Onderzoek in Zo.-Nederland (Geophysical and Geological Survey of Southeastern Netherlands), edited by L. U. de Sitter. Mededeelingen van de Geol. Stichting, Ser. C-I-3-No. 1 (1949). 372 pp. (1–261 in Dutch; 262–365 in English), 73 figs., 2 pls. Paper covers. Approx. 7.75×10.50 inches, 24 folded maps, charts, sections boxed, separate from text, approx. 8×11×2 inches. Uitgevers-Mij. "Ernest van Aelst," Maastricht. Price fl. 30.

As a war-time educational makeshift the geological department of the University of Leyden carried out a gravity (Askania torsion balance, Thyssen gravimeter) and magnetic (vertical intensity) survey of Southeastern Netherlands. In 1942 the geophysical party was reorganized as a temporary service of the government coal-mines. This publication is their final report. It is mainly in Dutch, about 261 pages, with an excellent English summary of about 104 pages; the 24 folded maps and most of the figures have English legends. Of the summary about 25 pages are given to geology, about 30 pages to theoretical considerations about gravity, and about 60 pages to a more detailed discussion of the results. There is also a geological and geophysical bibliography of 133 items.

The work was carried out by geologists and has the typical virtues and faults of such a survey. The virtues are that the authors never lose sight of the geological problems involved and use their geological knowledge in deriving a solution which is geologically probable. The vices are that the operators never lose sight of the geological problems involved and tend to concentrate their observations too closely in the interesting spots. For instance there are some lines less than a kilometer long and the spacing varies from 150 feet to 1,500 feet. The survey does not offend badly in this respect.

* Published by permission of the Director of the U. S. Geological Survey.

and some of the difficulties were due to local conditions of accessibility, etc., nevertheless I feel that most geophysicists would have distributed the stations more evenly.

In the geological summary we are told that "the geological history of Brabant-Limburg comprises two great periods, viz.: firstly, the Variscan orogenic and sedimentary cycle and secondly, the Alpine cycle. The Variscan cycle contains the history of the ancient Brabant mass and the development of the great Variscan foredeep of Devonian-Carboniferous age. The Alpine cycle is the history of the Lower Rhine embayment. These two great periods are separated by a long quiet period of sedimentation and intermediate emergence and abrasion, occupying the time from the Upper Permian to the Lower Jurassic." The older tectonic trends run WSW–ESE. The Lower Rhine Embayment transgresses over this from the northwest. In this embayment are numerous faults running NW–SE and dividing the region into four major units running roughly NW–SE—(1) The Kempen-South Limburg region to the southwest, (2) Roer valley graben (not to be confused with the German Ruhr valley which is sixty miles to the northeast), (3) Peel block, (4) Geldern-Crefeld horst. Most of the structures are well known from mining, drilling, etc. Thus there is good opportunity to check theory against fact. The problem was to outline the faults in detail more particularly where they were not known. The gravity map shows a flat minimum running NW–SE with a rather sharp rise on both flanks. Thus the gravity is governed mainly by the structures of the Lower Rhine Embayment, and is a good tool for mapping the faults.

Since the problem is closely concerned with faults one chapter discusses "The Dip of Large Tension Faults" from a geologic, mathematical, and model experiment viewpoint. Another chapter discusses the density differences, both direct and indirect measurements. One chapter discusses the accuracy of torsion-balance data, both from repeat measurements and from closed traverses. The conclusion is that the mean square error is 1.5 E. Yet in the gradient cross sections the points often lie well over 10 E off the average curve. There is no indication of what causes these large errors and none that the authors are aware that the survey is very inaccurate (whether unavoidably or avoidably). In the photographs there is no evidence of spade-work around the station which is nearly always very important. Those who are unacquainted with the torsion-balance work should not be misled by the inaccuracy of this survey. Usually it is possible to obtain much smoother data. The detailed discussion is on the whole good, though there are one or two rash statements such as: "the gradient vectors always point perpendicularly to the main originating phenomenon." The vertical magnetometer survey gave poor results "there is no obvious connection between the variations of the vertical intensity of the magnetic field of the earth and the major structural features as known from the Carboniferous surface."

H. RAINBOW,
Houston, Texas

PUBLICATIONS RECEIVED

Listed below are all publications received at the Business Office of the society on subscription and through free exchange for *Geophysics* since publication of the last issue. Periodicals and separates indicated by the asterisk (*) have been forwarded to the Special Reviews Committee, and will be placed in the permanent depository of the society at the University of Tulsa Library. These publications are available for loan to members of the society on application to the business manager. Other publications will be held for a short time at the Business Office.

Periodicals

American Journal of Science, Vol. 248, Nos. 2, 3, 4 & 5 (Feb.–May, 1950)
**Annales de Geophysique*, Vol. 5, No. 4 (Oct.–Dec., 1949)
**Annali di Geofisica*, Vol. III, No. 1 (Jan., 1950), Vol. II, No. 4 (Oct., 1949)
**Az Állami Földmérés Közleményei*, Vol. 1, No. 3 (1949)
**Boletin de la Asociacion Mexicana de Geologos Petroleros*, Vol. 1, Nos. 1 & 2 (Nov. & Dec., 1949), Vol. 2, No. 1 (Jan., 1950)
**Bollettino della Societa Sismologica Italiana*, Vol. XLI (1943–1948)
The Bulletin of the American Association of Petroleum Geologists, Vol. 34, Nos. 2, 3 & 4 (Feb.–Apr., 1950)
**Bulletin of the Hungarian Geological Society*, Vol. LXXIX, Nos. 1–4 (1949), Vol. LXXIX, Nos. 5–9 (1949)
**Bulletin of the Seismological Society of America*, Vol. 40, No. 1 (Jan., 1950)
**Canadian Geophysical Bulletin*, Vol. 3, No. 3.
**Documentation du Bureau Geologique* (Tananarive, Madagascar), No. 14 (1950)
Economic Geology, Vol. 45, Nos. 1 & 2 (Jan.–Feb. & Mar.–Apr., 1950)
**Erdöl und Kohle*, Vol. 3, Nos. 1, 2 & 3 (Jan.–Mar., 1950)
**Geofisica Pura e Applicata*, Vol. XV, No. 3–4 (Oct.–Dec., 1949)
**Geophysical Exploration* (SEG of Japan), Vol. 2, No. 3 (1949)
Institute of Petroleum Review, Vol. 4, Nos. 37, 38, 39 & 40 (Jan.–Apr., 1950)
**Publicaciones, Instituto de Fisiografia y Geologia* (Rosario, Argentina), No. XXXVI and No. H–1946 (1949)
Instruments, Vol. 23, Nos. 2, 3 & 4 (Feb.–Apr., 1950)
Journal of Applied Physics, Vol. 21, Nos. 1, 2, 3 & 4 (Jan.–Apr., 1950)
**Journal of the Chinese Geophysical Society*, Vol. 1, No. 2 (June, 1949)
Journal of Geophysical Research, Vol. 55, No. 1 (March, 1950)
Journal of the Institute of Petroleum, Vol. 36, Nos. 312, 313, 314 & 315 (Dec., 1949, Jan.–Mar., 1950)
**Nafta*, Vol. V, No. 12 (Dec., 1949) & Vol. VI, No. 1–2 (Jan.–Feb., 1950)
**Nuclear Science Abstracts*, Vol. 3, No. 12 (Dec. 30, 1949), Vol. 4, No. 2 (Jan. 30, 1950), No. 3 (Feb. 15, 1950), No. 4 (Feb. 28, 1950), No. 5 (Mar. 15, 1950), No. 6 (Mar. 30, 1950), No. 7 (Apr. 15, 1950), No. 8 (Apr. 30, 1950)
Physics Today, Vol. 3, Nos. 2 & 3 (Feb. & Mar., 1950)
**Proceedings of the Cambridge Philosophical Society*, Vol. 46, No. 2 (Apr., 1950)
**Publications of the Department of Mining and Metallurgy* (University of Technical Sciences, Sopron, Hungary), Vol. XVII (1948–1949)
**Quarterly Journal of the Geological Society of London*, Vol. CV, No. 1 (Nov. 19, 1949)
Review of Scientific Instruments, Vol. 21, Nos. 1, 2, 3 & 4 (Jan.–Apr., 1950)
**Revista Geominеraria*, Vol. X, No. 2 (1949)
**Transactions and Proceedings of the Geological Society of South Africa*, Vol. LI (Jan.–Dec., 1948)
**Works of the Geophysical Observatory in Swider* (Poland), Vol. 12 (1949)

CONTRIBUTORS

THOMAS BARDEEN

THOMAS BARDEEN received a B.S. degree in Electrical Engineering and an M.S. degree in Applied Mathematics from the University of Wisconsin in 1933 and 1934.

From 1934 to the present, Mr. Bardeen has been employed by the Gulf Research & Development Company, where he has devoted most of his time to the design and development of geophysical instruments. During the war he worked for several years on mines and mine countermeasures.

KENNETH C. CRUMRINE

KENNETH C. CRUMRINE was born November 2, 1910, in Independence, Kansas. He majored in physics at the University of Kansas where he received the A.B. degree in 1932 and the A.M. degree in 1933, held the E. E. Slosson Memorial Award and a state fellowship, and was elected to Phi Beta Kappa and Sigma Xi. He held a teaching fellowship at the California Institute of Technology where he received the Ph.D. degree in physics in 1937.

Engaged in electrical prospecting with the Shell Oil Company until 1940, he then joined the geophysical research laboratory of The Texas Company where he developed methods and instruments utilizing gamma rays and neutrons. He joined the geophysical research laboratory of The Carter Oil Company in 1946 where his research has been principally on electrical and surveying methods and apparatus. He is a member of the American Physical Society and the Society of Exploration Geophysicists.

MILLER QUARLES, JR.

MILLER QUARLES, JR. received B.S. and M.S. degree in geology at the California Institute of Technology at Pasadena in 1940 and 1941. He started for United Geophysical Company in the winter of 1941 after a few months employment with Lockheed Aircraft. He went through the routine of computer, surveyer, observer, seismologist, party chief, and supervisor while working in California, England, and the Mid-Continent. He flies his own Bonanza airplane in the course of supervising and belongs to the Aircraft Owners and Pilots' Association as well as the American Association for the Advancement of Science, American Geophysical Union, American Association of Petroleum Geologists, Society of Exploration Geophysicists, and Dallas Geophysical and Geological Societies.

In addition, references are cited to earlier issues for the biographies of: Maurice Ewing and Frank Press, Vol. XIII, No. 3 (July, 1948); C. Hewitt Dix, Vol. XIII, No. 1 (January, 1948); D. C. Skeels, Vol. XIV, No. 2 (April, 1949); E. A. Eckhardt, Vol. XIII, No. 4 (October, 1948).

SOCIETY ROUND TABLE

MEMBERSHIP APPLICATIONS APPROVED FOR PUBLICATION

The Executive Committee has approved for publication the names of the following candidates for membership in the Society. This publication does not constitute an election, but places the names before the membership at large. If any member has information bearing on the qualification of these nominees, he should send it to the president within thirty days. (Names of references appear in parenthesis after the name of each nominee.)

ACTIVE

Julian Curtis Ashby (O. C. Clifford, Jr., A. E. McKay, C. H. Hightower)
Milton Anthony Bohannon (W. M. Rust, Jr., Derry H. Gardner, W. D. Mounce)
David Jonathan Bratton (L. A. Scholl, Jr., Roy L. Lay, W. H. Gibson)
Eugene Russel Brumbaugh (Joseph C. Waterman, H. R. Thornburgh, Kenneth S. Cohick)
Kenneth McRuer Clark, Jr. (Roy L. Lay, A. A. Hunzicker, V. E. Child)
Lanham Todd Clark (Homer C. Moore, Jay P. Garner, Price E. Roberts)
John Joseph Collier (W. W. Newton, Donald M. Davis, J. E. Jett)
Ludwig Stanley Demshar (W. C. Lamb, W. B. Robinson, R. W. Jones)
William Thurman Evans (Alfred C. Winterhalter, John W. Millington, Robert L. Henson)
Cecil Kay Fielder (H. G. Patrick, D. P. Carlton, M. M. Slotnick)
F. Gassman (A. van Weelden, Walter Fisch, E. Poldini)
Theodore Stephen Green (W. L. Homan, L. D. Dawson, Frank B. Smith)
William John Gundlach (T. O. Hall, Chester Sappington, Earle W. Johnson)
Cecil Hagen (Don Jopling, Frank Fisk, Cecil Green)
Edward McGowen Hale (M. C. Terry, W. D. Mounce, D. H. Gardner)
Probhat Coomardas Hazra (Dart Wantland, Thomas P. Ahrens, J. L. Savage)
Lorimer Ward Hoar (H. M. Thralls, H. H. Andrews, B. F. Rummerfield)
John Chamberlain Hollister (L. T. Freeman, A. J. Hintze, J. E. Hawkins)
Arno Richard Kassander, Jr. (Chalmer J. Roy, W. Dudley Coursey, Dayton H. Clewell)
Anthony Joseph Kochendorfer (G. H. Westby, F. B. Leedy, N. K. Moody, Jr.)
Edwin Andrew Malone (L. J. Peters, L. W. Gardner, Carl L. Bryan)
Nacy Waters McGee, Jr. (G. H. Westby, F. B. Leedy, N. K. Moody, Jr.)
Perry Taylor McReynolds (H. L. Voelker, George W. Carr, J. B. Nichols)
Louis Francis Melchior (John E. McGee, Sigmund Hammer, L. L. Nettleton)
Edward John Northwood (T. Rozsa, Hans Lundberg, Harry Pearson)
James Richard Ording (Derry H. Gardner, Wm. M. Rust, W. D. Mounce)
Edwin Moats Pincomb (Roy L. Lay, B. H. Treybig, Jr., F. R. Coryn)
Newell Pottorf (Daniel Silverman, Joseph D. Eisler, C. E. Buffum)
Mary Collins Rabbit (L. Don Leet, Henry R. Joesting, Perry Byerly)
Carl Hertz Savit (Henry Salvatori, Dean Walling, V. E. Prestine)
George Dean Schedler (Albert J. Barthelmes, Harry Hugh Andrews, Clare Edmond McClure)
Robert Louis Schmidt (John J. Rupnik, L. O. Seaman, W. Lee Moore)
Harold Wright Stoneman (Geo. E. Wagoner, Paul L. Lyons, John O. Galloway)
August Eduard Susstrunk (E. J. Handley, Opie Dimmick, Richard Williams)
Stephen Thyssen-Bornemisza (C. A. Heiland, L. L. Nettleton, L. Mintrop)
Frank Bronson Tolman (T. P. Ellsworth, John W. Mathews, Robert J. Wells)
Charles Henderson Wallace (L. B. Trombla, R. H. Glover, James A. Ballard)
Kenneth Arvin Webb (H. V. Crowder, Samuel E. Sims)
Frederick Ervin Wright (R. Clare Coffin, K. C. Thompson, J. W. Fishback)

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John Call Cook (B. F. Howell, Sylvain J. Pirson, Lloyal O. Bacon)
Charles Warren Dick (R. D. DeJournette, Jr., Chester J. Donnally, George J. Shoup)
William Earl Neal Doty (R. F. Hughes, C. K. Jordan, Frank Searcy)
Joseph H. Evens (W. H. Courtier, C. C. Crenshaw, John Bondurant)
George Howard Fentress (William H. Courtier, A. J. Hintze, H. E. Stommel)
Jack Michael Flynn (A. W. Black, L. E. Whitehead, H. R. Prescott)
George David Glover (D. S. Hughes, B. E. Richert, H. L. Schiflett)
Walter Dean Grafton (C. W. Payne, James L. Morris, Lorenz Shŏck)
Leroy Glen Graham (E. D. Alcock, Lorenz Shock, Charles G. McBurney)
Grayson Michael Hajash (P. Lyons, F. Cady, S. Zimerman)
Edward Vernon Harrison (J. H. Todd, B. B. Strange, A. G. Harvey)
Andrew John Hayes (R. W. Olson, P. E. Haggerty, C. H. Green)
John Heads (E. J. P. van der Linden, A. A. Fitch, J. E. Woodburn)
John Harmon Henkel (W. J. Yost, C. D. McClure, C. F. Rust)
William Wahrmund Herpel (Robert S. Duty, Jr., J. A. Brooks, Jr., M. M. Slotnick)
Arthur Edward Hird, Jr. (John A. Adams, Chester J. Donnally, James G. Jackson, Jr.)
Friedrich Alexander Hoeninghaus, Jr. (R. H. Schmuck, H. L. Voelker, R. S. Epperson)
Lawrence Edward Hoover (H. G. Patrick, R. S. Duty, G. P. Montgomery, Jr.)
Hyman Kaufman (L. F. Athy, H. Prescott, F. Searcy)
Robert Jesse Leininger (E. V. McCollum, Craig Ferris, Tapley G. Arnold)
Arthur Vaughan Lewis, Jr. (V. E. Prestine, O. A. Strange, M. J. Walczak)
George Ambrose McCalpin, Jr. (B. E. Richert, H. W. Rose, James B. Macelwane, S.J.)
Edgar Owens McCutchen (C. J. Donnally, George Shoup, H. W. Straley, III)
Walter Albert McKee (Ray F. Keller, William H. McGuire)
Daniel Burch McKenzie, Jr. (C. E. McClure, D. B. Harris, H. M. Thralls)
Alan Carlyle Minnaar (Oscar Weiss, John Berning)
Theodore Joseph Mouche (Edward Schempf, B. W. Sorge, Raymond Peterson)
James Keith Nelson (F. Goldstone, L. K. Mower, R. B. Hale)
Charles Wesley Nicholls (Booth B. Strange, Chester J. Donnally, Robert T. Gallagher)
Richard Bedford Oldaker (Phil P. Gaby, C. M. Moore, Jr., John J. Babb)
Lawrence Norman Ott (Harold B. Morris, Erik Thomsen, Phil H. Garrison)
William Herbert Parsons (Phil P. Gaby, C. M. Moore, Jr., Ernest Kiesler)
Elwin Merrill Peacock (Cecil H. Green, R. F. Bennett, Eric Jonsson)
Howard J. Pincus (Milton B. Dobrin, W. Maurice Ewing)
Calvin Post (Norman J. Christie, Miller Quarles, Jr., William Howard Myers)
William Alexander Robertson (Phil P. Gaby, C. M. Moore, Jr., John J. Babb)

Billy Allen Rosser (Chester J. Donnally, George J. Shoup, Richard H. Wardell)
Roy Green Russell (Dupree McGrady, Fred DiGiulio, Harris Cox)
Ervine Edwin Rutledge (Robert D. Miller, F. Goldstone, Josiah Taylor)
Erwin Strieber Scholl (R. C. Barber, Philip Donnerstag, R. Henquet)
H. Schols (A. E. Brayton)
Barthlome Schorre (Robert S. Duty, Wm. B. Duty, A. Kohler)
Irvin Cathey Scott, Jr. (R. D. DeJournette, Jr., C. J. Donnally, G. J. Shoup)
Norman Fredrick Scott (Paul Lyons, F. Cady, S. Zimerman)
John Frederick Stickel, Jr. (J. A. Sharpe, A. F. Cline, J. C. Rollins)
Arthur Lamoreaux Stauffer (G. D. Jett, E. J. Handley, Richard Williams)
Robert Clifton Stone (Robert S. Duty, Jr., J. A. Brooks, Jr., James C. Porter)
Leon Edward Tabor (K. M. Lawrence, Francis F. Campbell, Andrew Gilmour)
Roy Walter Thompson (R. D. DeJournette, Jr., C. J. Donnally, George J. Shoup)
Garland Edward Tilley (S. B. Stewart, Donald Crary, R. F. Bennett)
Arthur Reginald Torode (R. H. Wardell, C. J. Donnally, G. J. Shoup)
Marshall Coleman Wicker (Robert D. Miller, W. Hafner, F. Goldstone)
James Roy Willcockson (Howard Itten, C. J. Long, D. W. Ratliff)
Cecil Quin Williams (B. B. Strange, Fred J. DiGiulio, W. H. White)

TRANSFERS TO ACTIVE

J. Randolph Strong, Jr.
Jeff E. Miller, Jr.
Lynn D. Ervin
W. N. Rabey

TRANSFER TO ASSOCIATE

Duncan M. Bowie

RESIGNATIONS

William T. Holser (Associate)
Louis J. Paddison (Associate)

MINUTES

ANNUAL BUSINESS MEETING

April 24, 1950

The Annual Business Meeting of the Society of Exploration Geophysicists was held in the Grand Ballroom of the Stevens Hotel, Chicago, Illinois. The meeting was called to order by President Andrew Gilmour at 2:00 P.M.

The minutes of the Annual Meeting held in the Gold Room of the Jefferson Hotel, St. Louis, Missouri, on March 14, 1949 were read by the Secretary and were approved as read.

The report of the Nominations Committee was given by President Gilmour, who is Chairman of this Committee. The results of the voting for new officers are as follows:

Number of ballots received	981
Number of ballots disqualified for non-payment of dues	7
Number of ballots disqualified for no signature	1

Results

For President:	
George E. Wagoner	569
Maurice Ewing	399
No vote	5
For Vice-President:	
Sigmund I. Hammer	538
Dayton H. Clewell	421
No vote	14
For Secretary-Treasurer:	
Francis F. Campbell	604
W. H. Courtier	346
No vote	23

Messrs. George E. Wagoner, Sigmund I. Hammer and Francis F. Campbell were, therefore, formally declared elected.

The report of Mr. E. V. McCollum, Chairman of the Standing Committee on Membership, was requested by the President. Due to the late date of formation of this committee, no report was made by Mr. McCollum.

The report of the Standing Committee on Honors and Awards was made by Mr. Cecil H. Green, Chairman. Mr. Green reported that Dr. Leo J. Peters would receive the award for the best paper and Mr. Fred J. Agnich would receive honorable mention. Dr. J. C. Karcher would be the recipient of the Honorary Membership award. These awards were to be presented at the Joint Session of the A.A.P.G., S.E.P.M., and S.E.G. at 9:00 A.M., April 25, 1950. The report was accepted and is attached as Exhibit A.

The report of the Standing Committee on Program and Arrangements was given by Vice President George E. Wagoner, who is Chairman of this Committee. His report was accepted and is attached as Exhibit B.

Reverend J. B. Macelwane, S. J., Chairman, presented the report of the Standing Committee on Education. The committee distributed a number of copies of the report to the audience for examination. The report was accepted and is attached as Exhibit C.

The report of the Standing Committee on Student Membership was given by Professor Ralph C. Holmer, Chairman. This committee recommended that a fellowship be administered by the Society. The report was discussed by Mr. W. T. Born, who suggested that the granting of a fellowship be delayed until sufficient contributions are obtained to establish a funded fellowship. Dr. J. A. Sharpe suggested that contributions be requested from all companies that operated geophysical crews, on a rated per crew basis, to obtain funds sufficient to establish the fellowship. Sufficient funds should be collected to establish a fellowship for each of five years. Mr. Gilmour stated that the remarks and suggestions would be considered by the Council. The Committee report was accepted and is attached as Exhibit D.

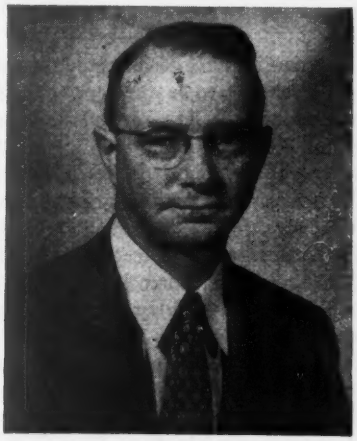
Mr. Paul L. Lyons, Chairman, gave the report of the Standing Committee on Public Relations. During 1949 this committee originated a considerable amount of publicity which was sent to various newspapers and trade journals throughout the country. The report was accepted and is attached as Exhibit E.

Mr. Francis F. Campbell, Chairman of the Standing Committee on Distinguished Lectures, presented the report of that committee. The report was accepted and is attached as Exhibit F.

The report of the Radio Facilities Committee was given by Chairman R. D. Wyckoff. The function and accomplishments of the committee were briefly reviewed by Mr. Wyckoff. In view of the importance of the work of this committee to the geophysical industry as a whole, an advance printing of this report was made in the April, 1950 issue of *Geophysics*, pages 264–266. The final report, in the Minute Book as Exhibit G, was accepted.

OFFICERS FOR THE YEAR ENDING APRIL, 1951

ANDREW GILMOUR, *Past President*



SIGMUND HAMMER, *Vice-President*

GEORGE E. WAGONER, *President*

FRANCIS F. CAMPBELL, *Secretary-Treasurer*

RICHARD A. GEYER, *Editor*

The report of the Special Committee on Review of Geophysical Activity was prepared as a technical paper which is to be presented as the first paper in the techniacl session immediately following the business meeting. The work of the committee was acknowledged by the President.

Milton B. Dobrin, Chairman, Special Reviews Committee, presented the report of that committee, which was accepted. It is attached as Exhibit H.

The Editor's report, given by Richard A. Geyer, Chairman, was read and accepted. The Editor's report included the report of the Standing Committee on Publications, W. M. Rust, Jr., Chairman. The combined report was accepted and is included as Exhibit I.

The Secretary-Treasurer, K. E. Burg, gave the report on the activities of the Executive Committee and the financial conditions of the Society. The report was illustrated by six slides. The report was accepted and is included as Exhibit J.

The President of the Society, Andrew Gilmour, expressed his thanks to the Executive Committee and the committee chairmen for their work and cooperation.

There being no new business to come before the Society, the meeting adjourned at 3:20 P.M.

Minutes prepared by K. E. Burg, Secretary-Treasurer.

K. E. BURG

EXHIBIT A. ANNUAL REPORT OF THE HONORS AND AWARDS COMMITTEE

April, 1950

In accordance with the Bylaws of the Society (Article X, Section 5), the Standing Committee on Honors and Awards was appointed by President Gilmour for the 1949–1950 period as follows:

Cecil H. Green, Chairman (1-year term)
Curtis H. Johnson (2-year term)
Frank Goldstone (3-year term)
Sidon Harris (4-year term)
Norman Ricker (5-year term)

At the outset of the current assignment the committee felt that its purpose was to consider prior to the Annual Meeting the important subject of honors under a two-fold category. The first task was that of selecting a single outstanding paper from those appearing in *Geophysics* during the previous calendar year, provided that one or more papers were recognized as reaching an arbitrary high standard in points of contained information as well as composition. The second task was that of selecting a new Honorary Member provided there was a candidate whose past work has exerted unusual influence upon the course of exploration geophysics.

Accordingly, the committee has transmitted the following unanimous recommendations to the Council in time for appropriate awards to be made at the present Annual Joint Meeting (Chicago, Illinois):

(a) For Best Paper of 1949—That by Leo J. Peters entitled "The Direct Approach to Magnetic Interpretation and Its Practical Application." The actual award comprises a special certificate and bronze plaque.

(b) For Honorary Membership—A single award to John Clarence Karcher represented by a certificate.

In addition, the committee has recommended that Fred J. Agnich be cited for Honorable Mention for his important paper entitled "Geophysical Exploration for Limestone Reefs."

In working towards the above recommendations, the committee evolved some rather important aspects relative to choice of papers which are here recorded for consideration at the present annual meeting of the Council and for guidance of the committee during next year.

The terminology "Best Paper," as applying to a specific year, might imply that the process is merely one of selecting a No. 1 paper without regard to level of absolute quality. The situation is certainly not one of such easy judgment inasmuch as all likely papers must be scrutinized in the light of principles set forth in 1947 by the first Awards Committee under chairmanship of R. F. Beers (see

Geophysics, Vol. XII, No. 3, page 510). Thus, the indication of "Award" only, without mention of "Best Paper for the Year," was considered as being possibly more truly representative of the committee's decision. However, it was noted that such abbreviated form of reference would introduce a degree of indefiniteness since there would then be no indication of,

(a) Whether or not parallel awards were being given, and,

(b) The amount of material examined in term of number of back volumes of *Geophysics*.

Consequently, the present award indicates "The Best Paper" and for the year "1949."

It should be noted that the present committee deviated enough from existing principles to recommend that F. J. Agnich's paper is deserving at least an Honorable Mention.

It may be desirable to develop a design for both certificates—that is, for Outstanding Paper and Honorary Membership—which would become standard in form and perhaps be embellished with a crest. To this end a contest might well be arranged among the membership at large soon after the present annual meeting for the purpose of obtaining design for an official crest or seal.

There seems to be some doubt that the previously elected Honorary Members were awarded certificates. Suitable action should be considered if this situation is confirmed.

I want to take this opportunity to express sincere appreciation to my fellow committee members for their complete cooperation in carrying out a most interesting assignment.

Respectfully submitted,

CECIL H. GREEN, *Chairman*

EXHIBIT B. REPORT OF PROGRAM AND ARRANGEMENTS COMMITTEE SOCIETY OF EXPLORATION GEOPHYSICISTS

April 24, 1950

Stevens Hotel, Chicago, Illinois

Chairman of the Program and Arrangements Committee is automatically selected by the election of the Vice President of the Society.

Other members of the Committee are as follows:

Sigmund Hammer, Pittsburgh, Pennsylvania
J. Lamar Worzel, New York, New York
O. F. Ritzmann, Washington, D. C.
C. A. Heiland, Denver, Colorado
C. E. Chesher, Calgary, Alta., Canada
Paul E. Nash, Dallas, Texas
W. W. Newton, Dallas, Texas
James L. Morris, Ft. Worth, Texas
Roy L. Lay, Houston, Texas
Robert L. Palmer, Houston, Texas
Homer G. Patrick, Houston, Texas
Joe B. Hudson, Los Angeles, California
John Sloat, Bakersfield, California
R. M. Wilson, Shreveport, Louisiana
J. Ryan Walker, Shreveport, Louisiana
J. P. Garner, Tulsa, Oklahoma
J. E. Hawkins, Tulsa, Oklahoma

Thirty-three papers were submitted for presentation. Twenty-six were selected and seven were rejected. Those rejected were not rejected due to quality but on account of a fully subscribed program. The excellent facilities for this meeting were arranged for by Mr. J. P. D. Hull, Business Manager, Elmer W. Ellsworth, Assistant Business Manager of the American Association of Petroleum Geologists, and Colin C. Campbell, Business Manager of the Society of Exploration Geophysicists.

Respectfully submitted,

GEO. E. WAGONER, *Chairman*

EXHIBIT D. REPORT OF COMMITTEE ON STUDENT MEMBERSHIP

April 22, 1950

We have on our rolls at present 281 student members, 49 of whom are foreign. This represents a net increase of 36 since December 31, 1949 when we had a total of 194 domestic and 51 foreign student members. On December 31, 1948 we had a total of 102 student members; therefore, during 1949 there was a net increase of 143. During 1949 we had an increase of 517 members of all classes. This indicates that 27.7% of all new members during 1949 were students.

During 1949 students at the University of St. Louis organized a geophysical society which became affiliated with the S.E.G. in March 1950. This increased the number of student chapters to three, the other two being located at the University of Tulsa and the Colorado School of Mines. It has been reported that students at the University of Houston are also interested in forming a student society.

The activity of your Committee on Student Membership has been mainly concerned with a further consideration of the suggestions made by the previous Committee that the S.E.G. sponsor a scholarship or fellowship fund.

In order to investigate the degree of financial and moral support oil companies and geophysical contractors would lend to such a fund, one hundred and fifty-six questionnaires were sent to S.E.G. members making up a cross section of the geophysical industry. Fifty-two replies were received, of which forty-one were the questionnaires, and eleven were letters.

The following are the questions included in the questionnaire with a tally of the answers:

QUESTIONNAIRE

In consideration of the proposal that the Society of Exploration Geophysicists set up and sponsor a fellowship fund.

1. Does your company already award an undergraduate scholarship in geophysics? Yes: 0 No: 40
2. Does your company already award a graduate fellowship in geophysics? Yes: 2 No: 38
3. If either of the above answers are affirmative, please state name of school where scholarship and/or fellowship is placed, and amount of yearly stipend.
   St. Louis University—$1200
   California Institute of Technology
   Part Time Employment of 2 students at Southern Methodist University
   Part Time Employment of 1 Student at Tulsa University
   This list is obviously not complete. It is noted that the two graduate fellowship in geophysics at the Colorado School of Mines were not reported. No doubt other scholarships or fellowships in geophysics were likewise not reported.
4. From your company's standpoint, are you in agreement with the principle of setting up a scholarship and/or fellowship fund under the sponsorship of the S.E.G.? Yes: 22 No: 13
5. Do you think your company would financially support such a fund to the extent of annual payments of the amount of: None: 10; Less than $50: 5; $50: 9; $100: 5; More than $100: 1.
6. Assuming sufficient financial support, should the annual stipend be: $500: 1; $800: 10; $1000: 15; More: 4.
7. In the event financial support is sufficient for assisting only one student, would you suggest setting up first: the undergraduate scholarship: 10; or the graduate fellowship: 18.
8. Should the scholarship or fellowship be designated by the name Donald C. Barton? Yes: 23; No: 7; S.E.G.: 5; Geophysics: 1; Geophysical Industries: 1.
9. Would you prefer that the fund be set up on a loan rather than a fellowship basis until such a time that its yearly earnings would constitute the fellowship stipend? Yes: 14; No: 16.
10. Do you think that we should solicit nominal contributions from individual members of the S.E.G.? Yes: 12; No: 22.

Other suggestions and remarks made on the questionnaires and by letter included a great diversity of opinion. The remarks varied from the unfavorable, "Do not believe companies, contractors, or members should be solicited for this purpose," to the favorable, "We believe that the idea of setting up a scholarship fund is excellent and should be encouraged morally and materially. We are most interested in seeing this idea succeed, and in this connection you can be assured of our willingness to support financially this cause."

The majority opinion was somewhere in the middle of these two extreme views. Some of the large oil companies indicated that support could probably be given after some plan was actually in operation. The majority of the support, however, was indicated by the geophysical contractors. It is doubtful that the contractors felt that they were required to support a fellowship plan. Many of the contractors felt perfectly free to voice an unfavorable opinion. The independence of the American contractor, whether geophysical or otherwise, was quite evident.

In the main, the opinion was more favorable to the fellowship fund than unfavorable. This was certainly shown by the answers to the questionnaire. However, regardless of the over-all opinion, we *have* sufficient financial support, about $1200, indicated in the answer to question 5 of the questionnaire, to set a fellowship plan in operation, if such is the wish of the members of the S.E.G.

It is recommended that a fellowship fund be set up and sponsored by the Society of Exploration Geophysicists under the following plan:

1. The Student Membership Committee should be assigned the task of soliciting financial support for a graduate fellowship fund, with the funds payable to the S.E.G. through the business manager. This committee should also publicize, through the business manager, the details of the application dates, etc.

2. A committee should be appointed to consider the applicants, and to choose the recipient of the award. The members of this committee should have academic interests, but should not be on the faculty of any institution teaching geophysics. The choice of the recipient of the award should be made not only on the basis of the man and his background, but also on his choice of thesis material. Research of a fundamental nature should be favored as doing the most good for the greatest number. A paper based on the recipients research sponsored by the S.E.G. should be presented to *Geophysics* for publication.

3. The amount of the annual stipend should be no more than $1000, and may be $100 less than the amount available in the fund. A list of the contributors should be published in *Geophysics*.

It is earnestly requested that the Council consider these recommendations.

Respectfully submitted,
RALPH C. HOLMER, *Chairman*
H. V. W. DONOHOO
V. L. JONES
LOUIS SLICHTER

EXHIBIT E. REPORT OF THE PUBLIC RELATIONS COMMITTEE

1949–1950

The membership of the public relations committee for the term 1949–1950 is as follows:

Paul L. Lyons, Chairman
H. M. Thralls
T. R. Shugart
H. E. Prokesh
R. F. Bennett
P. J. Kempsky
B. B. Burroughs

In fulfilment of its duties, the committee reports the following activities during the past year. These are reported in some detail, so as to serve as a basis for future programs.

1. Eighteen national news releases were distributed. The policy adopted on these is as follows:
   a. The releases are written out completely, in conventional newspaper style, so that they may be published with no rewriting. This adds to the chances of publication, improves accuracy.
   b. The releases are sent to 81 addresses, using a mimeograph service company available in Tulsa. The list includes newspapers in the oil cities, the oil journals and news services, scientific journals, news syndicates, officers of the society, and members of the publicity committee.
   c. Since the publicity chairmen of the various sections constitute the public relations committee, it is their responsibility, upon receipt of a news release, to contact the editors of local newspapers in order to influence the publication of the release. This is most important, and it is absolutely necessary that section publicity chairmen be chosen who will conscientiously carry out this duty as part of their assignment.
2. The committee handled the publicity for the first Distinguished Lecture tour of the Society as follows:
   a. An article concerning Drs. Merle Tuve and Howard Tatel was distributed to editors of the papers in the cities where they spoke Mats were sent with the articles, for it was felt that the sending of mats rather than pictures would insure publication of pictures.
   b. The committee sent all program chairmen of local sections involved complete file on all biographical data, and all recently published news releases involving Drs. Tuve and Tatel and the Carnegie Institution, so that the presidents of the various sections could have this data for proper introduction of the speakers
3. News releases were distributed covering all regional meetings of the society. The committee successfully solicited, in cooperation with the public relations committee of the Geophysical Society of Tulsa, advertisements for the program of the Dallas regional meeting of November 17 and 18, 1949.
4. The committee publicized completely the candidates nominated for the executive committee. This included pictures and individual news stories to the newspapers of each candidate's home city and to his college alumni publications. Similar releases were made up again when the results of the mail ballot election were known.
5. The committee duly publicized the formation of new sections of the society.
6. The committee duly reported all honors bestowed upon members of the society, supplying pictures and releases.
7. Abstracts of convention papers and other convention news were supplied to journals well in advance of the convention. News releases concerning the convention were prepared in advance and sent to the mailing list for release during the progress of the convention.
8. All past presidents of the society were notified by mail to be present for a group picture if in attendance at the Chicago convention.
9. A pamphlet entitled 'History of the Society of Exploration Geophysicists,' prepared by the committee, was distributed to all new members during 1949 through the business manager.
10. An article was written for the magazine "Physics Today" concerning the 1949 convention of the society. The article appeared in the June issue.
11. The committee answered in full all letters of inquiry directed to it. This item alone amounted to approximately fifty letters.
12. Arrangements were again made with "The Geophysical Directory for 1950" for free inclusion in that publication of a statement of the society's aims and a list of national and section officers.
13. Arrangements were made as usual for publication of E. A. Eckhardt's paper, "Geophysical Activity in 1949," in the convention issue of *The Oil and Gas Journal*.
14. The committee contacted Father Linehan, S. J. of Boston University, a member of the society, when it learned that he was to lead an expedition to obtain a gravity, magnetic, and

seismic profile across Greenland. The committee made arrangements to contact him daily by short wave radio, with S.E.G. to have the right to publicize all news and scientific data acquired. At the last minute, the U. S. Navy withdrew permission for the venture.

15. The committee during the year again proposed that a prepared list of questions regarding the current and future status of geophysical methods and ideas be sent to all leading geophysicists. It is proposed to use the results of such a poll to write a number of articles to be published in newspapers and journals. The executive committee, upon consideration, proposed that a committee be set up to handle this proposed poll. The public relations committee recommends that such a committee be selected and the poll be taken, so as to provide the committee with authoritative news items for distribution.
16. The committee, upon obtaining permission of the executive committee, has prepared a standardized list of geophysical map symbols paralleling the new list adopted by the U.S.G.S. Geologic Map Symbol Committee. The list, when and if adopted, is recommended for publication in *Geophysics* so as to standardize geophysical symbols used in published maps.
17. The committee recommends that writers of geophysical papers for the society be allowed, upon request, to prepare digests of articles for release to trade journals prior to publication of the complete article in *Geophysics*. This recommendation stems from the numerous requests for such articles from magazine editors.
18. In conclusion, the committee emphasizes that publicity is of great importance to the science of geophysics, and that sound publicity must constantly be presented to the oil industry and to the public.

Respectfully presented,
PAUL L. LYONS, *Chairman*

EXHIBIT F. REPORT OF THE DISTINGUISHED LECTURE COMMITTEE

The Distinguished Lecture Committee became a standing committee of the Society of Exploration Geophysicists at the 1949 Council Meeting in Chicago. Mr. Andrew Gilmour appointed Mr. John H. Wilson of Fort Worth, Texas, to serve as a member for three years; Mr. R. C. Dunlap, Jr., of Bakersfield, California, to serve two years; and Francis F. Campbell of Tulsa, Oklahoma, to serve one year and as chairman of the committee. Although no meetings of the committee have been held, views have been exchanged by letter.

The committee made tentative plans for two lecture tours for the 1949–50 season. One of them was carried out successfully. Dr. Joseph A. Sharpe of Tulsa persuaded Dr. Merle A. Tuve, Director of the Department of Terrestrial Magnetism of the Carnegie Institution of Washington, D. C., to be the first distinguished lecturer. Dr. Tuve suggested that Dr. Howard Tatel accompany him on the tour and give part of a lecture on "Current Magnetic and Seismic Studies of the Carnegie Institution of Washington." An itinerary was arranged in January, 1950, which included lectures, laboratory visits, and social events in Houston, Shreveport, Dallas, and Tulsa. Details of the tour are given in *Geophysics* in the reports of the meetings of local sections.

The travel expense of Dr. Tuve amounted to $180.00. This cost was allocated by the committee among the societies in the cities where the lectures were given. The Fort Worth Geophysical Society was a joint sponsor of the Dallas lecture and shared in the cost. No lecture was scheduled in Fort Worth because of the limitation placed by Dr. Tuve on the number of his appearances. The travel expense of Dr. Howard Tatel was borne by the Carnegie Institution.

For the 1950–51 season the committee is considering two tours: one in November which would coincide with the fall meeting of the Pacific Coast section, and another in January or February. The Distinguished Lecture Committee is not planning more than two tours in one season because it is of the opinion that the local sections should bear the primary responsibility for originating programs.

The committee appreciates the cooperation of the older sections in the first lecture tour, and will welcome the cooperation and suggestions of all the sections, new and old, in future plans.

FRANCIS F. CAMPBELL, *Chairman*

EXHIBIT H. REPORT OF THE SPECIAL REVIEWS COMMITTEE

1949–1950

The following members of the Society were appointed by the Editor in the spring of 1949 to serve for two years on the Special Reviews Committee:

Arthur A. Brant
J. Brackett Hersey
Nelson C. Steenland
Milton B. Dobrin, Chairman
Francis F. Campbell
Kenneth L. Cook
C. G. Dahm
A. J. Hermont

The function of the Committee is to keep the membership of the Society properly informed on the more significant current literature of geophysics published outside the Society's own journal. This is done through reviews written or solicited by members of the Committee for publication in *Geophysics*.

The four issues of *Geophysics* from July, 1949 to April, 1950 contained thirty-two reviews of recent books or papers relating directly or indirectly to geophysical prospecting. The reviews were prepared by eighteen persons, who were either members of the Special Reviews Committee or specialists requested by members to write the reviews because of their particular competence. More than two-thirds of the items reviewed were from foreign sources. Ten were books, 21 papers or articles in periodicals, and one a new geophysical journal. Six of the reviews were based on publications from Great Britain, five from France, four from Germany, two from Sweden, and one each from Canada, Australia, Switzerland, Finland, Russia and Italy. Foreign language material included French, German, Russian and Italian.

In addition to the Committee members, the following members of the Society generously contributed their time and efforts to write the reviews published during the year:

Charles C. Bates
Mark E. Burgunker
Hubert Guyod
Richard H. Hopkins
Richard A. Geyer
Alex Frosch
Myron T. Kozary
James B. Macelwane, S. J.
Silvain J. Pirson
Frank Press
W. M. Rust, Jr.
J. L. Worzel

Sigmund Hammer

To insure the most complete possible coverage of the geophysical literature, the Reviews Committee has worked closely with Mr. Colin C. Campbell, Business Manager of the Society, in proposing exchanges of *Geophysics* for all geophysical publications not presently on the Society's exchange list. Book publishers have been generous in contributing copies of books for review when requested and often send them to the Society without solicitation.

The Chairman takes this opportunity to thank the members of the Committee for their generous participation in its work, all those who have contributed reviews, and Mr. Campbell for his very considerable efforts in the Committee's behalf.

MILTON B. DOBRIN, *Chairman*

EXHIBIT I. EDITOR'S REPORT

This report is for the period April 1949 to April 1950, representing the first year of the present Editor's term of office. Thirty-two technical papers totaling 389 pages were included in the four issues of *Geophysics*. In addition, 127 pages of patents and 28 pages of reviews constituted the remainder of the technical material printed.

An analysis of the source of papers appearing in *Geophysics* from 1936 through 1949 was compiled by the Editor and published in the Society Round Table Section of the April issue. Four hundred and fifteen technical papers were published during this period and a detailed summary and statistical evaluation of the sources on an annual basis were tabulated.

An effort was made to obtain a number of papers from geophysicists outside of the United States. This policy is being pursued in an attempt to promote closer coordination between geophysicists as an aid in understanding and coping with geophysical problems on a global scale. In this regard, papers by geophysicists in England, Holland, Italy, Germany and Turkey were published.

The present Editor, as have so many others in the past, wishes to express his appreciation to Mr. O. F. Ritzmann for so ably carrying out his time-consuming and very accurate compilation of the Patent Section which has grown from 116 patents per year in its initial form to 760 during the past year. The exceptional efforts on the part of the Special Reviews Committee with Dr. Milton B. Dobrin as Chairman in making available to the membership of the Society such a long list of diversified reviews are also hereby acknowledged. A more detailed report of the Committee's activities compiled by the Chairman is appended to this report.

The Editor is particularly indebted to a number of persons for so ably assisting him in the varied aspects involved in preparing *Geophysics* for publication, including the members of the Standing Committee on Publications and especially its Chairman, Dr. W. M. Rust, Jr.; Mr. Colin C. Campbell, the Society's Business Manager; and Miss Mary Jo Clark, Assistant to the Editor. In addition, the work of Mr. C. A. Wiese and his associates of the Banta Publishing Company should also be mentioned for their excellent cooperation in publishing *Geophysics*, including so cheerfully coping with the eccentricities of the Editor and many of the authors.

RICHARD A. GEYER

EXHIBIT J. REPORT OF THE SECRETARY-TREASURER

The report of the Secretary covers the period from March, 1949 through April, 1950. All action of the Society during the past fiscal year took place during the business and Joint Council meetings, during an informal Executive Committee meeting, and through Executive Orders.

An Executive Committee meeting, on an informal basis, was held during the Regional Meeting in Dallas on November 18, 1949. The status of the duties of the various members of the Executive Committee was discussed and several minor matters were discussed which were handled at a later date by Executive Orders.

A total of 45 Executive Orders was instituted, of which 29 concerned applications for membership, transfers, reinstatements, resignations and expulsions.

The more important matters handled by Executive Orders included:

The final approval of the application of the Ark-La-Tex Geophysical Society for affiliation as a local section was given on March 2, 1949.

On March 24, 1949, approval was given to present bound volumes of *Geophysics* to Student Sections.

The monthly salary of the Business Manager's assistant was increased from $175.00 to $185.00 per month.

Storage space for all back issues of *Geophysics* and other publications was rented at a location near the business office and all such issues were shipped to Tulsa from the printers in Menasha, Wisconsin.

A decision to request an increase in membership dues and subscription rates was reached on October 13, 1949 and the intention to make this increase was published in *Geophysics*, January, 1950.

The November, 1949 Dallas meeting was designated as a Regional Meeting of the Society.

A new contract was negotiated with the printers of *Geophysics*, George Banta Publishing Company, and the base order for printing was increased from 2,000 to 3,000 copies of each issue.

The Permian Basin Geophysical Society was accepted as a local section by Executive Order dated January 20, 1950.

Affiliation of the St. Louis University Geophysical Society as a student section was approved February 7, 1950.

The agenda for the Joint Council Meeting to be held during the 1950 meeting was prepared by the Business Manager.

REPORT ON MEMBERSHIP

	1949	*1948*	*1947*	*1946*
Active Members	1,597	1,446	1,302	1,178
Associate Members	494	271	220	186
Student Members	245	102	68	12
Honorary Members (living)	3	3	3	3
	2,339	1,822	1,593	1,379
Increase over prior year	517	229	214	116

Preparation of the minutes of the Business Meeting and Joint Council Meeting held on April 24 and April 25 completed the work of the Secretary.

KENNETH E. BURG, *Secretary-Treasurer*

The report of the independent accountants for the year 1949 follows:

PRICE, WATERHOUSE & CO.

1221 Locust Street
St. Louis 3
May 8, 1950

To the Executive Committee,
Society of Exploration Geophysicists,
Tulsa, Oklahoma.

We have examined the balance sheet of the Society of Exploration Geophysicists as at December 31, 1949 and the statement of net loss for the year then ended. Our examination was made in accordance with generally accepted auditing standards and included such tests of the accounting records and such other auditing procedures as we considered necessary in the circumstances except that, as instructed, we did not apply the customary procedure of confirming receivables by direct communication with debtors.

The office staff is too small to permit the establishing of an effective system of internal control, and we therefore extended our tests of the transactions beyond those necessary where an adequate system is in force. While we did not make a detailed audit of all of the transactions, we compared the recorded cash receipts in totals with deposits shown on the bank statements for the year and examined paid checks, cash vouchers, and supporting data for disbursements.

Except for the change in policy of accounting for cost of special publications referred to in the note to accounts, which change has our approval, the principles of accounting maintained by the society during the year were consistent with those of the preceding year.

In our opinion, subject to the foregoing comments relating to receivables and to the system of internal accounting control, the accompanying balance sheet and statement of net loss present fairly the position of the society as at December 31, 1949 and the results of its operations for the year, in conformity with generally accepted accounting principles.

PRICE, WATERHOUSE & CO.

SOCIETY OF EXPLORATION GEOPHYSICISTS
BALANCE SHEET—DECEMBER 31, 1949

ASSETS

Cash		$11,381.17
Accounts receivable:		
Membership dues	$ 606.30	
Other	2,590.43	
	$ 3,196.73	
Less—Reserve for bad debts	700.00	
		2,496.73
Inventory of publications (see note)		—
Investment in United States Savings Bonds, at cost		13,880.00
Office equipment	$ 1,282.37	
Less—Reserve for depreciation	485.90	
		796.47
		$28,554.37

LIABILITIES

Accounts payable		$ 243.68
Federal insurance contributions tax		26.40
Deferred income:		
Membership dues	$ 7,372.83	
Subscriptions to and advertising in *Geophysics*	2,054.11	
		9,426.94
Surplus:		
Balance, December 31, 1948	$24,253.91	
Net loss for the year, per accompanying statement	(5,396.56)	
		18,857.35
		$28,554.37

Note to accounts—

In 1949 the society adopted a policy of amortizing the cost of special publications whereby no profit on sales thereof is recorded until the cost has been returned in full; any balance of cost is reduced to a maximum of one half the cost of unsold copies at the end of the year of publication and is written off at the end of the subsequent year. Accordingly, publication costs for the year 1949 were greater by an amount of $9,729 than would have been the case if the policy had not been so changed; such amount represented the remaining cost of special publications unsold at December 31, 1949.

Furthermore, the accounts do not reflect the inventory of back numbers and reprints of *Geophysics*, the cost of which was charged off at time of original publication.

Society of Exploration Geophysicists
Statement of Net Loss
for the Year Ended December 31, 1949

INCOME:			
Membership dues		$11,372.00	
Publications:			
Advertising	$ 7,942.78		
Subscriptions	3,008.17		
Back numbers	2,470.34		
Reprints	782.47		
Discounts allowed	(912.82)		
Geophysical Case Histories, Vol. I	13,284.76		
Cumulative Index to *Geophysics*	296.40		
		26,872.10	
Interest received		187.50	
			$38,431.60
EXPENSES AND PUBLICATION COSTS:			
Salaries:			
Business manager		$ 4,375.00	
Office assistant		2,170.00	
Commissions:			
Advertising—business manager		1,441.55	
Advertising—agencies		1,046.90	
Subscriptions—agencies		333.26	
Office and storeroom rent		906.67	
Stationery and office supplies		1,820.65	
Postage		929.77	
Telephone and telegraph		439.03	
Annual meeting		237.53	
Auditing		375.00	
Depreciation of office equipment		207.90	
Advertising		194.52	
Provision for bad debts		562.80	
Federal insurance contributions tax		72.12	
Oklahoma sales tax		40.84	
Miscellaneous		256.29	
		$15,409.83	
Publication costs (see note to accounts)		28,418.33	
			43,828.16
Net loss			$ 5,396.56

AWARD FOR BEST PAPER OF 1949

THE DIRECT APPROACH TO MAGNETIC INTERPRETATION AND ITS PRACTICAL APPLICATION

Geophysics, Volume Fourteen

DOCTOR LEO J. PETERS

Recipient, Award for Best Paper of 1949

Doctor Peters (left) receives the Certificate and Plaque from President Gilmour

FIFTH AWARD OF HONORARY MEMBERSHIP
CITATION

E. A. ECKHARDT

JOHN CLARENCE KARCHER—

For many years the reflection seismograph has been the most extensively used means of geophysical exploration employed by the oil industry. If its development can be credited to a single man, you are unquestionably the one. Although the abstract idea of reflections of sound energy from underground formations preceded you by a few seasons, it was not until you devoted yourself to the problem that the idea was implemented with equipment and procedures that rapidly transformed an idea into the most important technique available to geophysical prospecting today.

DOCTOR JOHN CLARENCE KARCHER

Recipient, Fifth Award of Honorary Membership

April 25, 1950

During World War I, you were engaged at the U. S. Bureau of Standards in developing sound ranging equipment. Such equipment found use at the fighting fronts in Europe for locating the position of enemy guns. The airborne sounds of their discharge passed over an array of microphones, which signalled electrically the arrival times of the airwave to a central recording station. From the geometry of the microphone array and the recorded time differences, the position of the source of sound could be determined with accuracy and dispatch. This background of experience in sound ranging and in equipment and system development undoubtedly had great influence on the subsequent trend of your activities and provided fertile ground for the germination of the reflection seismograph.

Among your associates at the U. S. Bureau of Standards were W. P. Haseman, Burton C. McCollum and the speaker. You, son of the oil country, contributed materially to their awareness of the problems of oil exploration and stimulated thought about new means for solving them. Dr. Haseman undertook to raise funds in Oklahoma to pay the cost of experimental work and the Geological Engineering Company was formed in 1920. You designed and built the special equipment required and purchased what was needed and available. In the spring of 1921, you headed west for Oklahoma where field work was to be done. The equipment in your trunk included a shovel. You were equally prepared to get off the concrete, physically or technically.

Your experimental program involved the investigation of both reflection and refraction techniques. The field as well as all other work was done competently, energetically and with imagination, but it finally had to be abandoned for lack of further financial support. The lack of success was only

Fifth Award of Honorary Membership for Outstanding service to Exploration Geophysics; Doctor Karcher (left) receives the certificate from Doctor Eckhardt
(Photo by Oscar, Chicago)

apparent and not real. Under more favorable circumstances, substantially the same equipment and the same techniques were later successful.

Had the refraction experiments been made over a salt dome in the Gulf Coast and the reflection experiments not been concentrated on relatively shallow reflections, the 1921 field season of the Geological Engineering Company would undoubtedly have been followed immediately by commercial application of the seismograph method. When Dr. Mintrop's parties arrived in the Texas Gulf Coast some three years later, they were no better prepared to discover salt domes in that area than you were at the end of your 1921 field work. Reflection work on shallow horizons remains to this date among the more difficult problems to handle. The problems presented to you for experimental attack were far from being most suitable to insuring your success.

In 1925, you became vice president and manager of the Geophysical Research Corporation, the first American company organized to do seismograph work. Your first crew went to work for Gulf early in 1926, and it was quickly followed by others. Many men who joined you in this expanding work have become leaders in the geophysical profession. G.R.C. and its alumni have furnished nearly half the presidents of S.E.G.

During the next few years, your crews discovered many salt domes and during the same years the development of the reflection technique engaged your attention. By 1927 commercial reflection surveys and discoveries were being made in Oklahoma.

Because of the relative scarcity of correlatable reflections, the Gulf coastal area was found to represent a special problem area for reflections. The first G.R.C. crew to do reflection work in this area was employed by Gulf, and its first reflection survey was made in 1929 over the Hankamer dome in S. E. Texas.

In 1930, you and some of your colleagues organized Geophysical Service, Inc., and this, in turn, has since become the parent of other well-known geophysical contracting organizations.

For these and other achievements too numerous to mention, we salute you

Pioneer among American geophysicists.

Active, imaginative and practical developer of ideas, men and equipment which have contributed materially to the outstanding world leadership of the United States in geophysical prospecting.

The most outstanding contributor to the development of the reflection seismograph method.

Past president of S.E.G.

The Society has expressed its respect and admiration for you by electing you to honorary membership. It gives me great satisfaction to have been the spokesman for the society on this occasion and to hand you this certificate of honorary membership.

Presidents of the society at the 1950 meeting. Left to right, standing: H. B. Peacock (1941); W. T. Born (1940); R. D. Wyckoff (1943); Cecil H. Green (1947); Henry C. Cortes (1945); J. J. Jakosky (1946). Seated: George E. Wagoner (1950); Andrew Gilmour (1949); E. A. Eckhardt (1939); L. L. Nettleton (1948); Eugene McDermott (1933). Present at the meeting but not in the picture: Paul Weaver (1932); J. C. Karcher (1937).

INCREASE IN MEMBERSHIP DUES AND SUBSCRIPTION PRICES

The Council, in the annual Joint Council Meeting on April 25, 1950, amended the By-laws of the Society as follows:

1. Article IV, Section 2 of the By-laws shall read:
   "The annual dues of an Active or Associate Member of the Society shall be seven dollars and fifty cents ($7.50), which includes the cost of one subscription to the Society's Journal."
2. Article IV, Section 3 of the By-laws shall read:
   "The annual dues of a student member of the Society shall be four dollars and fifty cents ($4.50), which includes the cost of one subscription to the Society's Journal."

Accordingly, the price of non-member subscriptions to *Geophysics* was increased to nine dollars ($9.00) per year. This action was taken on the recommendation of the Executive Committee published in *Geophysics*, Vol. XV, No. 1 (January, 1950), pages 158–159.

Under Article XVI of the Constitution (*Geophysics*, Vol. XV, No. 2, page 326) all actions of the council are subject to review by the members.

IRE WEST COAST CONVENTION

The Institute of Radio Engineers extends a cordial invitation to all members of the Society of Exploration Geophysicists to attend the "IRE West Coast Convention of 1950." The convention is being held in the Municipal Auditorium in Long Beach, California, September 13, 14 and 15, 1950. Being held in conjunction with the convention is the Sixth Annual Exhibit of the West Coast Electronic Manufacturers Association.

NAVY ARCTIC FILMS AVAILABLE FOR PUBLIC SHOWING

Naval films showing Operations in Alaska have now been released for showing before engineering societies and similar technical organizations. Formerly restricted to use by military engineers and affiliated personnel these films are now available on a loan basis from District Naval Training Aids Libraries or prints may be purchased through the U. S. Office of Education. Consisting of a series of five reels and entitled "U. S. Naval Operations in Alaska," the pictures are on 16 mm. film, in full color with complete narration.

In commenting on the scripts Dr. Vilhjalmur Stefannson, veteran Arctic explorer, who acted as one of the technical advisors stated that . . . "This is a much better script than I have ever seen with any Northern film . . . and in my opinion shows a basic understanding of the problem . . . "Produced for the U. S. Naval Bureau of Yards and Docks and sponsored by Commodore William G. Greenman, Director of Naval Petroleum Reserves, the films were started in 1947, took approximately two years to make and were just recently declared available for general public use.

A brief description and running time of each of the films in the series follows:

"MN-5377A-Introduction" has a running time of 18 minutes and discusses the general topography and climate of Northern Alaska during the winter and summer months. Problems of adequate clothing, food, housing and transportation as met by the Eskimo and white man are considered in detail.

"MN-5377B-Exploring for Oil" tells the geological and geophysical methods of exploring for oil in terms of an Arctic expedition. The techniques of core-hole drilling and deep test well-drilling are discussed and illustrated. Among the surveying methods considered are those using the aerial magnetometer, the gravity meter and the seismograph. Running time is 30 minutes.

"MN-5377C-Logistics" runs 20 minutes and covers the methods of logistic support of operations in the Arctic from the base camp, Point Barrow, Alaska. Procedures employed in loading, unloading and the warehousing of material in the Arctic are discussed and illustrated. The functions of the base camp and the methods employed in the logistic support of satellite camps and mobile field parties with the petroleum reserve also are considered.

"MN-5377D-Equipment" shows the types of equipment used in construction and transportation in the Arctic and the modifications and maintenance necessary for efficient cold-weather operations. 21 minutes.

"MN-5377E-Construction" discusses the many and varied problems encountered in construction in work in permafrost in the Arctic and how they have been met. 21 minutes running time.

These films are still being used for military training and prints may not be available immediately upon request. Therefore, it is suggested that the desired date and at least two alternate dates be included at the time original request is made.

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OinC, TAL, Navy No. 128, c/o FPO, San Francisco, Calif.

OinC TAL #2, Navy No. 926, c/o FPO, San Francisco, Calif.

PERSONAL ITEMS

M. E. MORROW and E. JACK HANDLEY announce the organization of MIDWESTERN GEOPHYSICAL LABORATORY, located at 2803 West 40th Street in Tulsa, Oklahoma, pending completion of its ultra-modern plant at 3131 South Harvard Avenue. The building, comprising 22,000 square feet of floor space, will contain the laboratory for the development and manufacture of geophysical equipment and other industrial instruments, and will provide headquarters for the company's seismic exploration contract work.

WALLACE E. PRATT, Honorary Member, was awarded the Kemp Medal by Columbia University for "distinguished service in geology" at a dinner program in the Men's Faculty club on May 4, 1950. Presentation was made by President Dwight D. Eisenhower.

JAY P. GARNER was recently elected president of Oil Exploration, Inc. Upon graduation from Rice Institute of Houston in 1935 Mr. Garner was employed by The Texas Company. He remained in the geophysical department of that company until 1945, and in 1946 he assisted in organizing Oil Exploration, Inc., a geophysical company specializing in seismic surveys.

MAURICE KAMEN-KAYE has resigned his position as chief geologist of Caracas Petroleum S. A. He is now located at Room 1363, Lincoln Building, 60 East 42nd Street, New York 17, N. Y.

H. H. BRONS has returned to B.P.M. (Royal Dutch Shell), taking up duties as chief geophysicist for the Nederlandsche New Guinea Petroleum Maatschappij with residence at Sorong, Netherlands New Guinea.

V. J. MIKE MERCIER has been appointed division manager for Kansas operations of Perforating Guns Atlas Corp., Houston. Formerly sales manager for Mountain Iron & Supply Co., he took up his new duties on May 1st, and will maintain headquarters in Wichita.

L. A. SCHOLL, JR. has been promoted to Geophysical Consultant on the General Manager's staff, Producing Department, The Texas Company, and ROY L. LAY has been advanced to Division Manager, Geophysical Division, Producing Department.

In making the announcement, E. R. Filley, General Manager, Producing Department, said both appointments are effective April 1.

The two Texaco officials have had a combined experience of over 50 years in both domestic and foreign operations of the company.

Mr. Scholl was born in Pittsburgh, Pa., and was graduated from Carnegie Institute of Technology with the B.S. degree in mining engineering. He also received the E.M. degree from the School of Mines, Columbia University, in 1916.

Starting with the old Producers Oil Company, a Texaco subsidiary, that year as a geologist, he was promoted to division geologist at Tulsa in 1918.

Mr. Scholl was made chief geologist, Houston, in 1920 and soon was transferred to Venezuela, where he remained until July 1925.

Following a year of graduate study at the University of California, he became consulting geologist, New York. In 1929 he was made chief of the Geophysical Division, Houston.

He was appointed manager of the division on September 1, 1945.

Mr. Lay, a native of Yoakum, Texas, worked for Geophysical Research Corporation for several years after his graduation from Rice Institute, Houston, Texas, with a B.S. degree in electrical engineering in 1928.

On April 11, 1932, he was employed by The Texas Company as a party chief in the Geophysical Division at Houston. After four years with Texaco Development Corporation at Houston, he was made supervisor of field crews, Geophysical Division, in 1937.

He was supervisor of a geophysical party which operated in Egypt in 1938, returning to Houston, in October of that year.

Mr. Lay was named assistant chief of the Geophysical Division, July 1, 1943, and became Assistant Division Manager on September 1, 1945.

Promotion of B. H. TREYBIG, JR., to Assistant to Division Manager of the Geophysical Division, Producing Department, The Texas Company, effective July 1, 1950, was announced by R. L. Lay, Manager, Geophysical Division.

Mr. Treybig, who will be located in the Division Office, Houston, is a native of Yoakum, Texas and attended Rice Institute. He was employed by The Texas Company in 1932. After working in various jobs in the Geophysical Division, he was promoted to seismic party chief in February, 1936.

In 1939 he served six months in Venezuela, where he had charge of the company's geophysical operations. He did extensive exploration work in the United States, then was assigned to Canada for six months during 1941.

Since July 1, 1944, he has been Supervisor of Geophysical Operations in the Louisiana Division, Producing Department, with headquarters in New Orleans.

Mr. and Mrs. Treybig have three children.

Professor ATHELSTAN SPILHAUS, Dean of the Institute of Technology, University of Minnesota, has been named Deputy Chairman of the Committee on Geophysics and Geography of the Research and Development Board, Department of Defense, to succeed Dr. W. W. Rubey of the United States Geological Survey.

Professor Spilhause, who has served as an alternate member of the committee since its formation in December, 1948, is one of five civilian members who serve on the committee. Dr. W. E. Wrather, Director of the Geological Survey, Department of the Interior, is chairman, and other civilian members are Dr. P. E. James, Professor of Geography, Syracuse University, Syracuse, New York; Dr. Horace Byers, Department of Meteorology, University of Chicago; Samuel B. Morris, General Manager and Chief Engineer, Department of Water and Power, Los Angeles, California; Dr. Richard Joel Russell, School of Geology, Louisiana State University, Baton Rouge. Two representatives each from the Army, Navy, and Air Force complete the membership of the committee.

Dr. H. E. Landsberg is executive director of the committee secretariat which has its headquarters in the Pentagon.

GEORGE HAYMOND HARRINGTON

(1903–1949)

On the night of October 21, 1949 George Haymond Harrington with Orville A. Sweitzer, Jr. piloting his plane, left Tulsa, Oklahoma for their homes in Houston, Texas. From the time of their departure from Tulsa, they should have arrived in Houston by 10 P.M. When they failed to arrive and no word was received, it was assumed that they had been forced down somewhere in between Tulsa and Houston. A diligent search was started early the next day and lasted for several weeks. After no trace was found of the passenger, pilot or plane, it was assumed that they had crashed and had been killed. This proved to be the case as the bodies and plane were found by Mr. Johnston, of the forestry service, on Winding Stair Mountain of the Kiamichi Mountains of Southeastern Oklahoma. From reports of persons who viewed the wreckage, death came instantly to both men.

George was born in Salem, West Virginia on July 3, 1903 to Ada Haymond Harrington and George Herbert Harrington. He attended grade school in West Virginia and was graduated from Tulsa High School in 1921. He attended the University of Arkansas for two years. After leaving the University of Arkansas, he enrolled in University of Michigan where he received a B.S. degree in geology in 1926. Before graduation, he married his sweetheart, Doris Gladden of Bentonville, Arkansas, who was also a student. Doris survives him as do his three sons, David 23, a senior geology student at the University of Texas, Bruce 17, and Denny 11, both students of St. Johns School in Houston.

Following graduation, George was employed by the Tidal Oil Company of Tulsa as a geologist. Two years later he joined the Barnsdall Oil Company as geologist. He was made geophysical coordinator when Barnsdall opened offices in Houston in 1932. When he left Barnsdall in 1939, he was their Chief Geophysicist. He joined Yegua Corporation after leaving Barnsdall and was President of this corporation at the time of his death.

He was a member of St. John's the Divine, Episcopal Church of Houston, Texas. He was a member of the Sigma Chi Fraternity. He was an active member of both the S.E.G. and the A.A.P.G., the Houston Geological Society, the Houston Club, Petroleum Club of New Orleans, and Brae Burn Country Club.

For sake of brevity, many things of George's background and experiences have been omitted, but these few words will sum them up for all who knew as did the writer: he was a top flight geologist, a good geophysicist, a fine husband and father, and a wonderful companion and friend.

T. I. HARKINS
May, 1950

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Meetings on second Thursday, each month, October to May, inclusive, at 7:00 P.M. in Lorton Hall on University of Tulsa Campus. Visiting geophysicists are always welcome.

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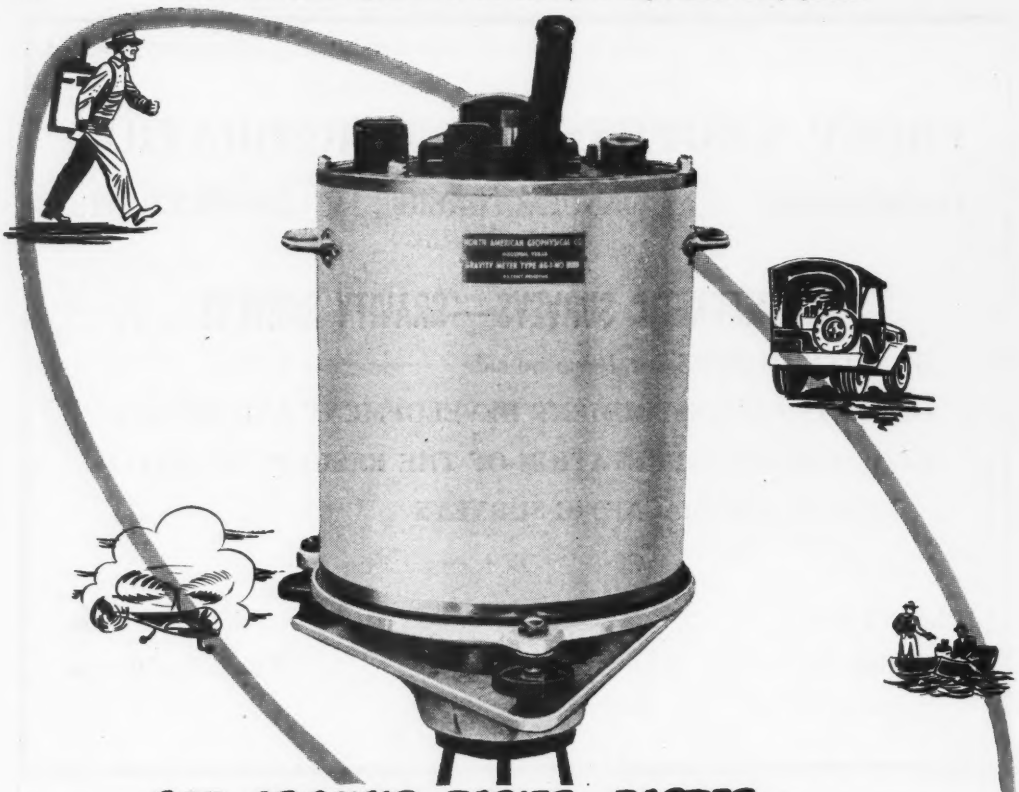

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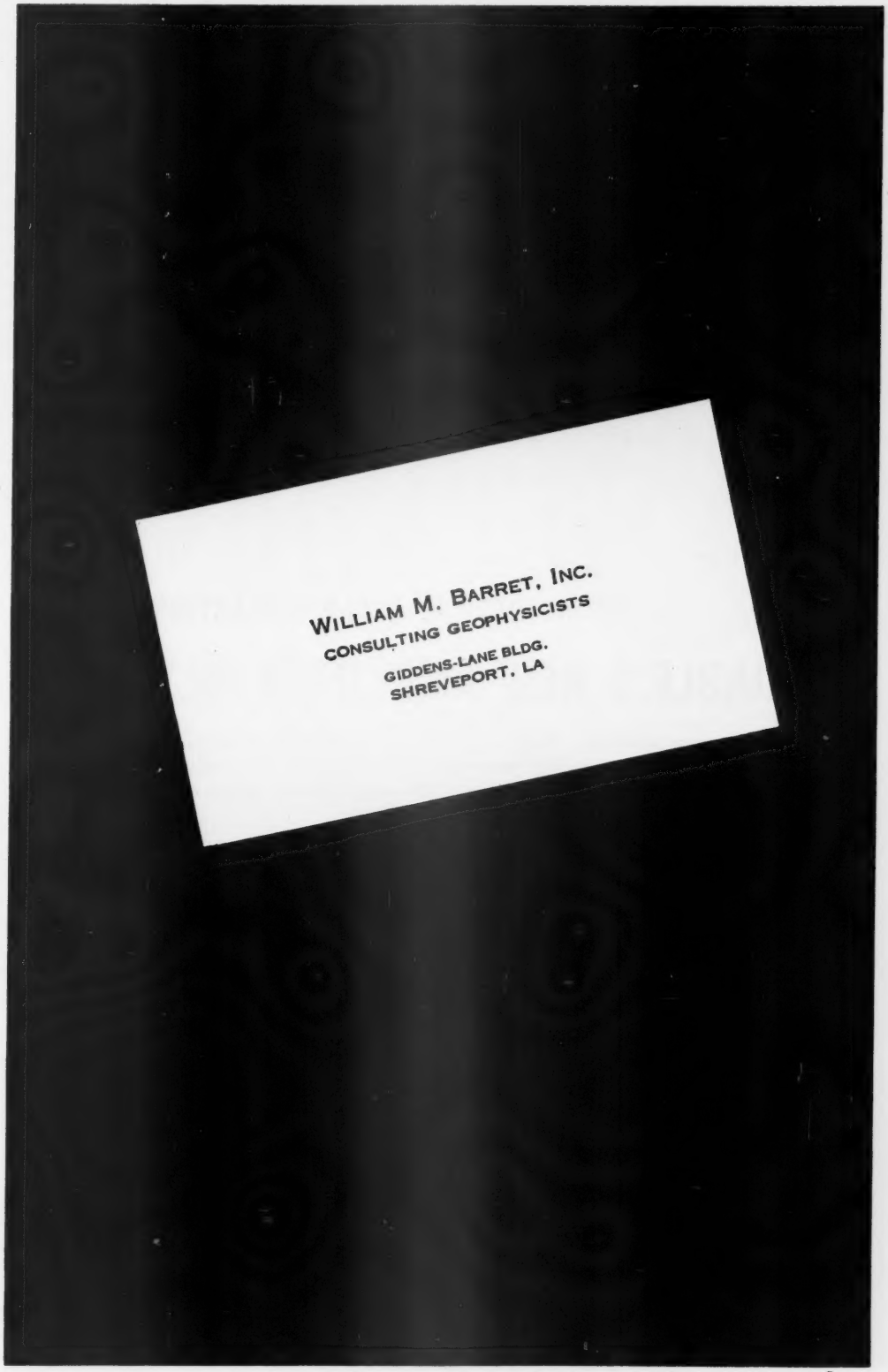

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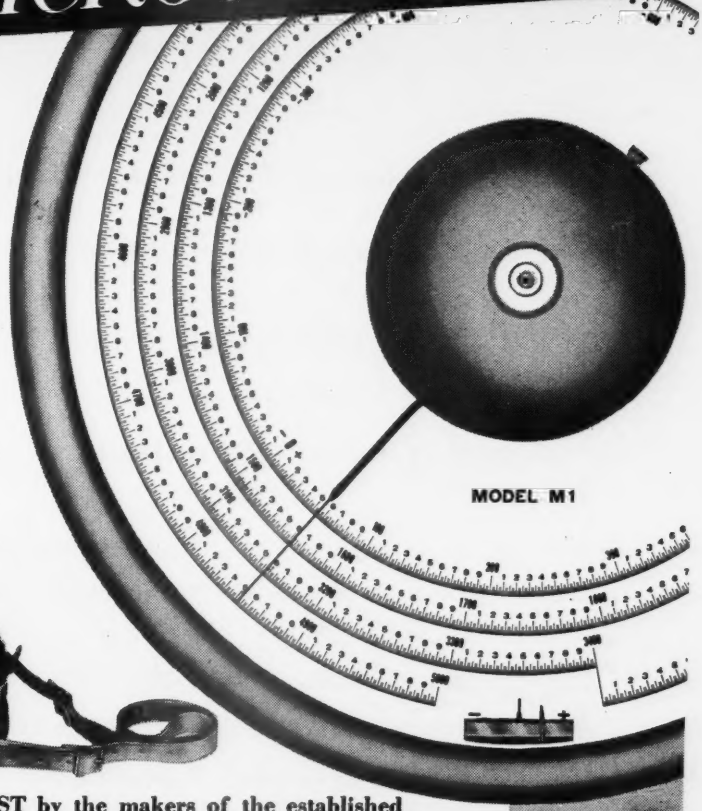

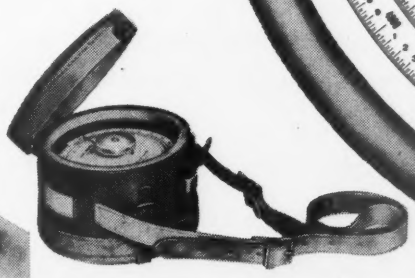

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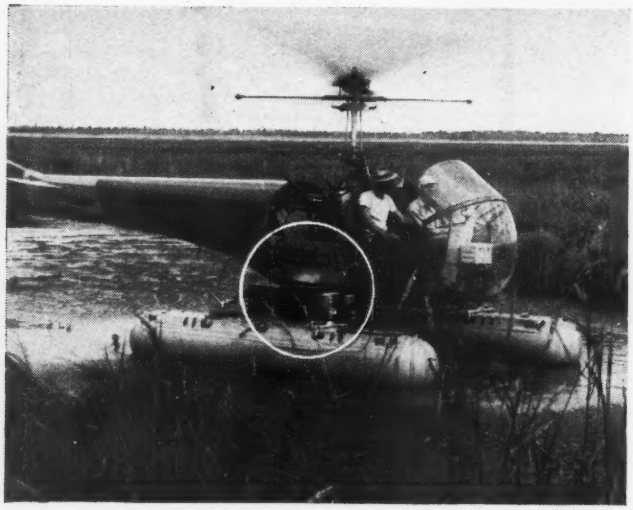

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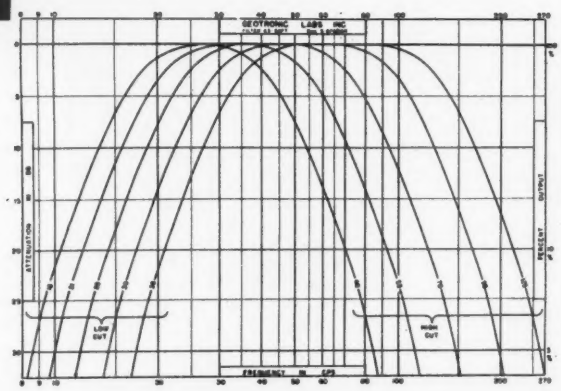

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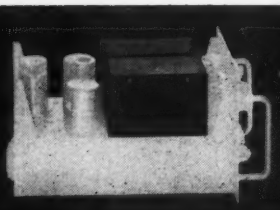

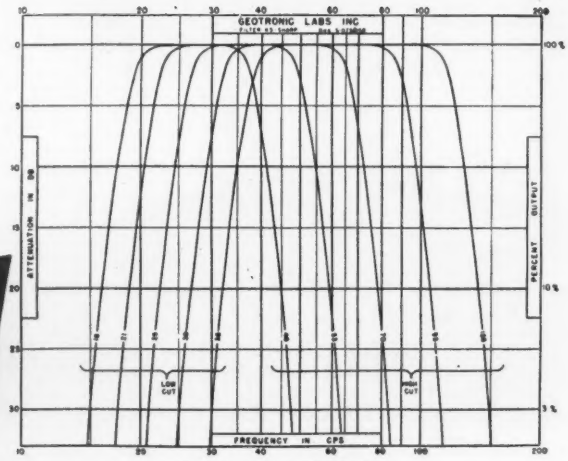

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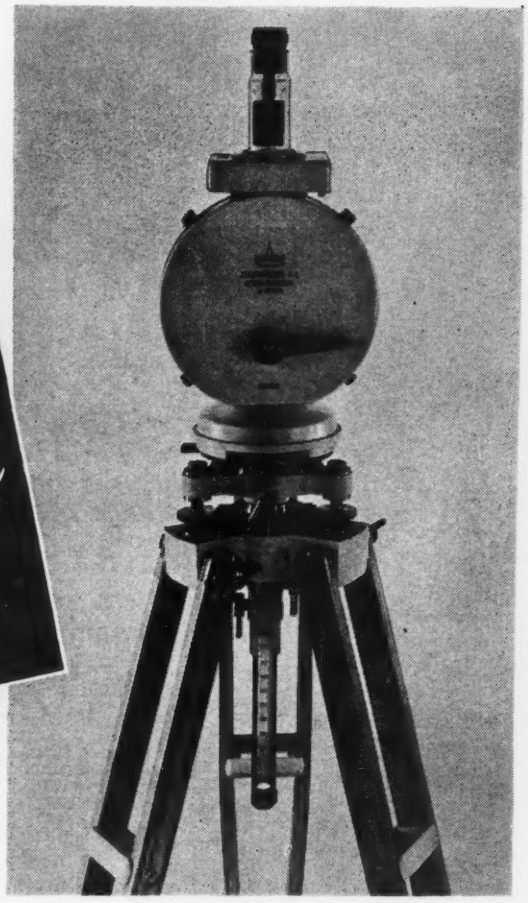

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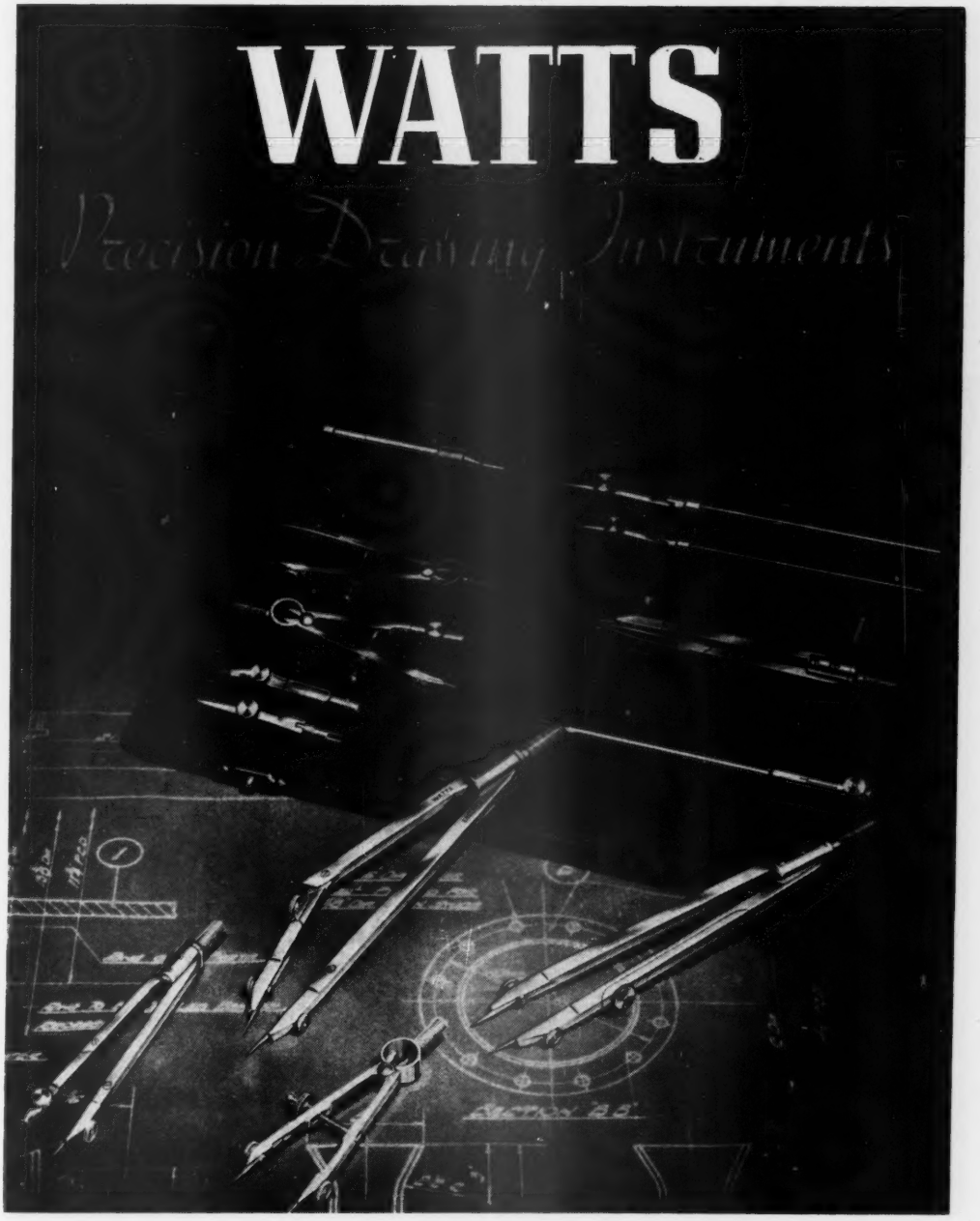

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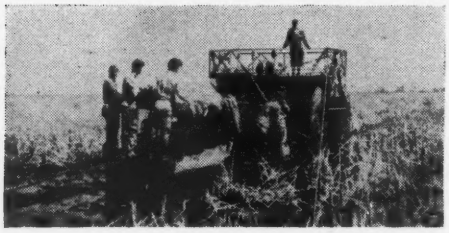

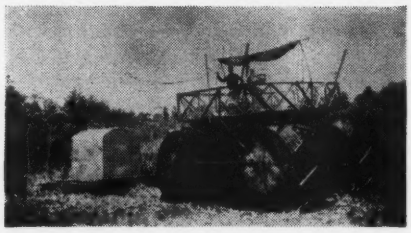

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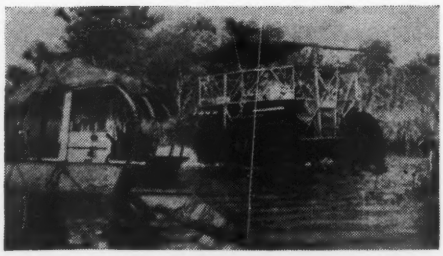

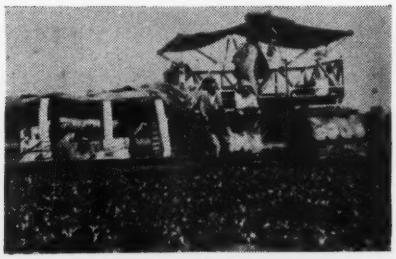

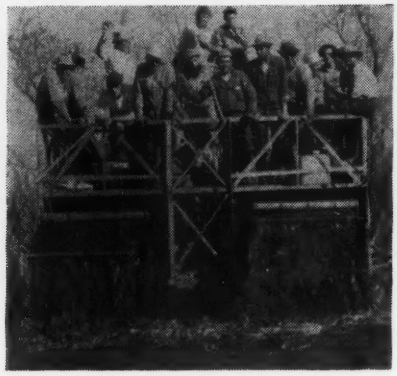

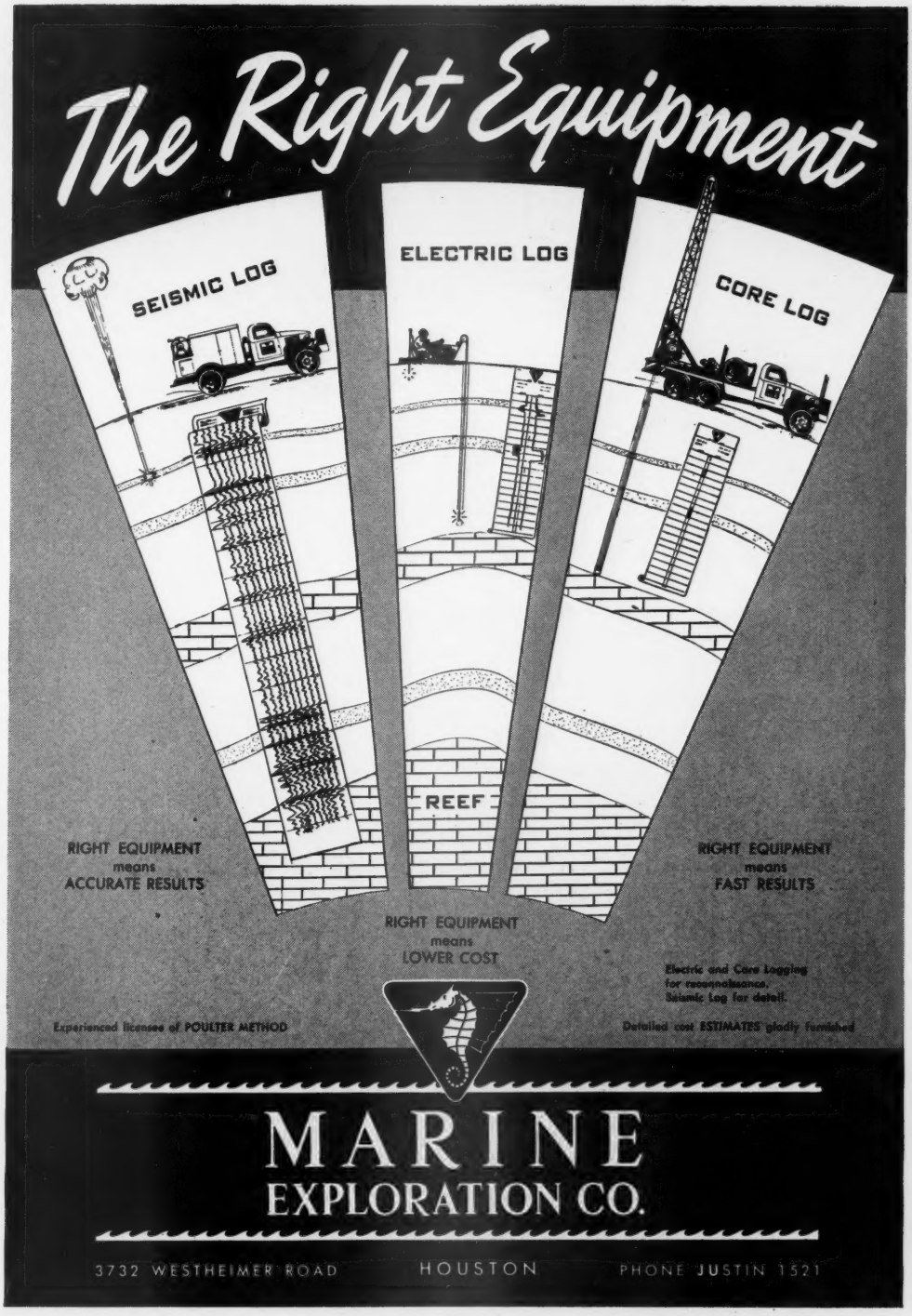
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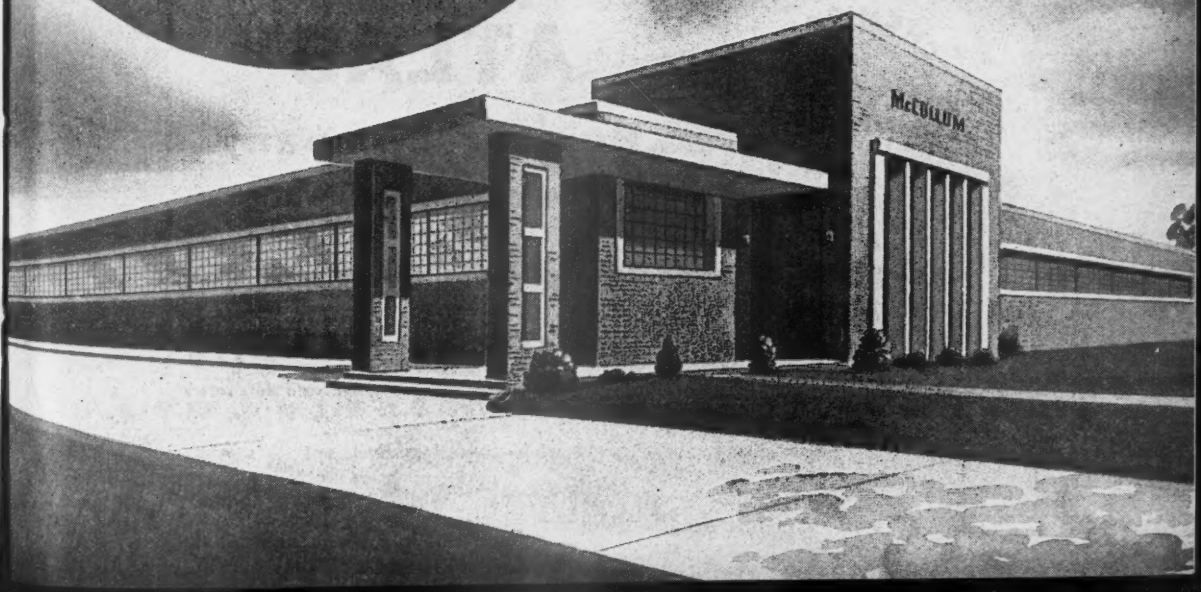

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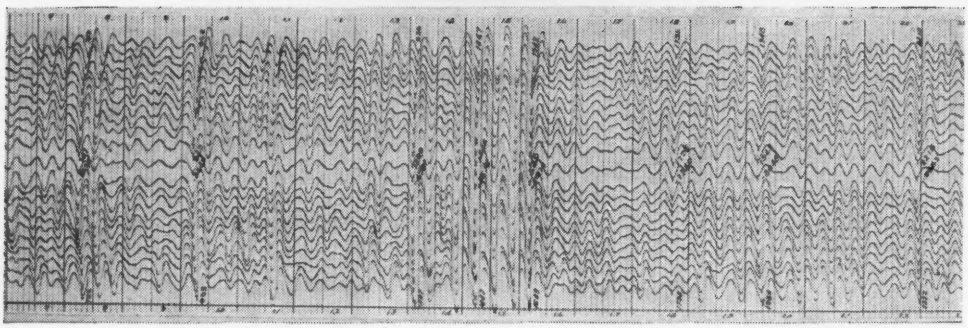

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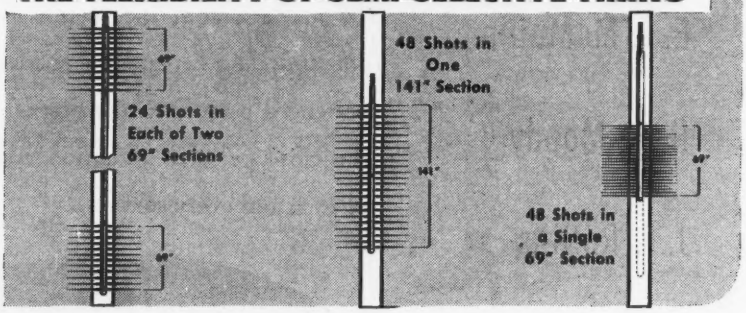

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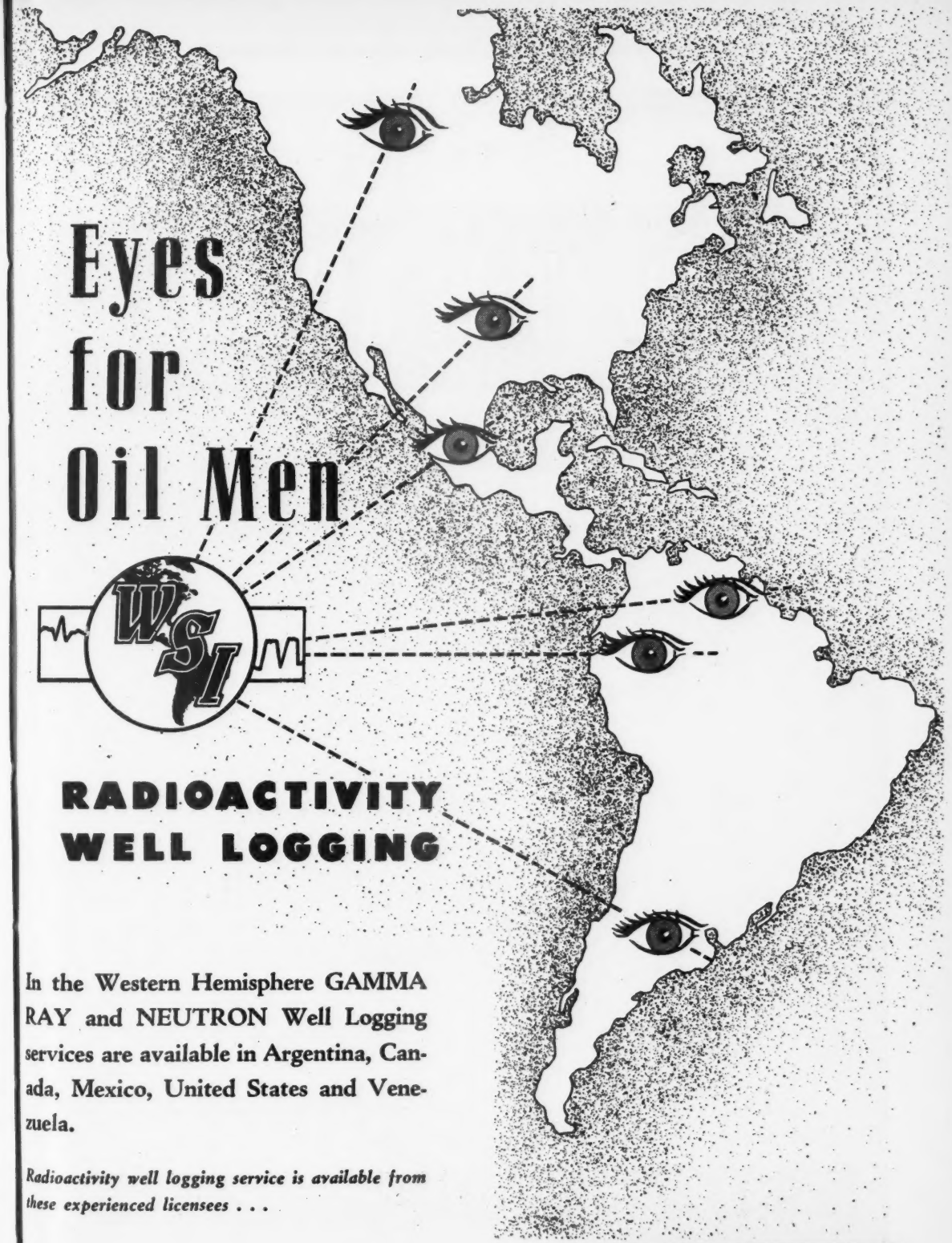

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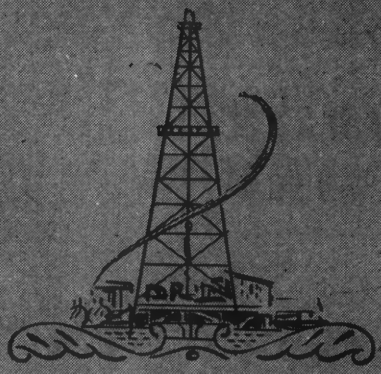

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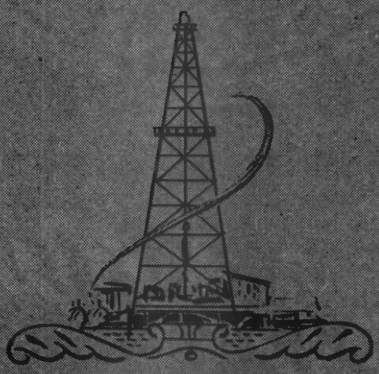

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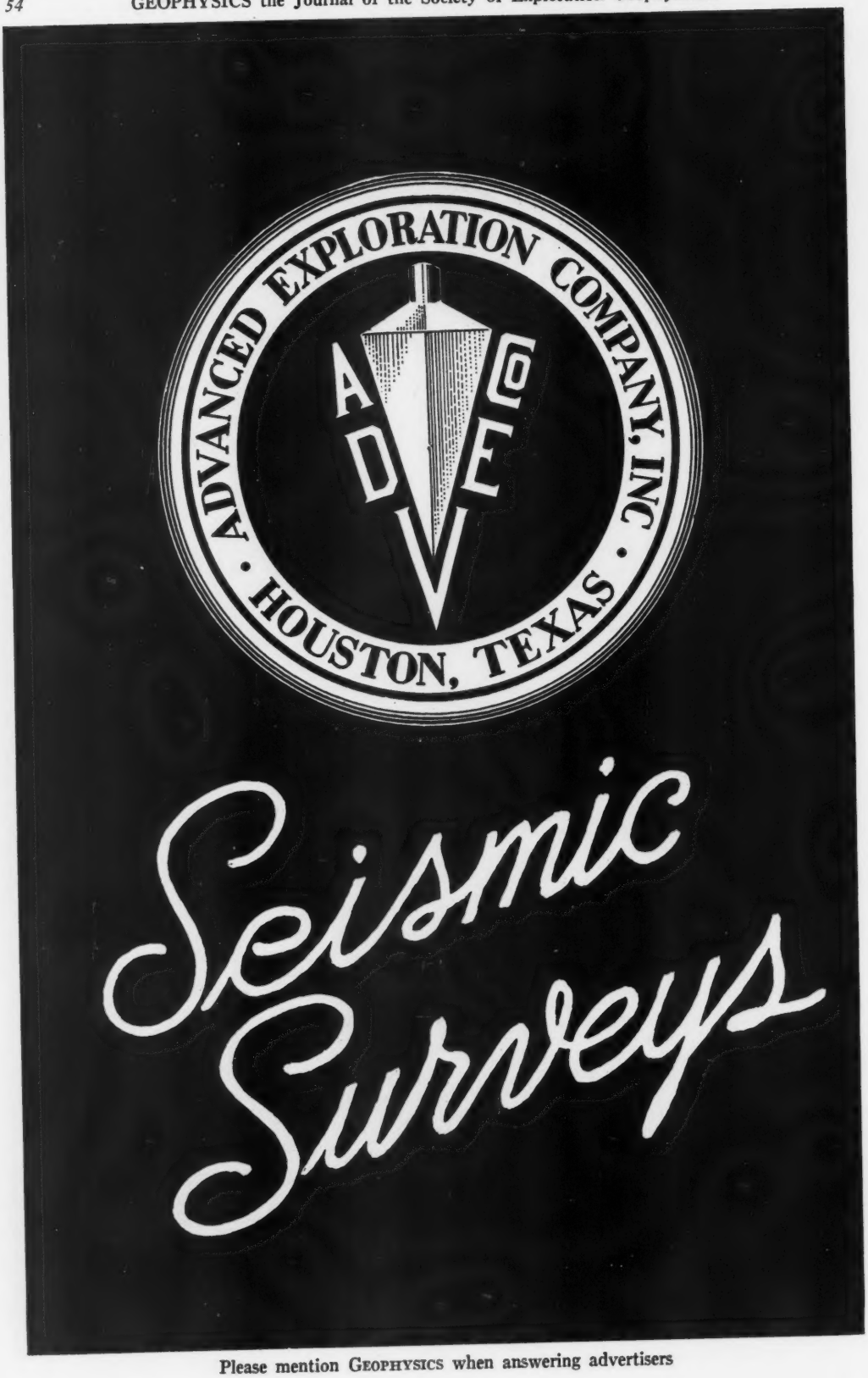
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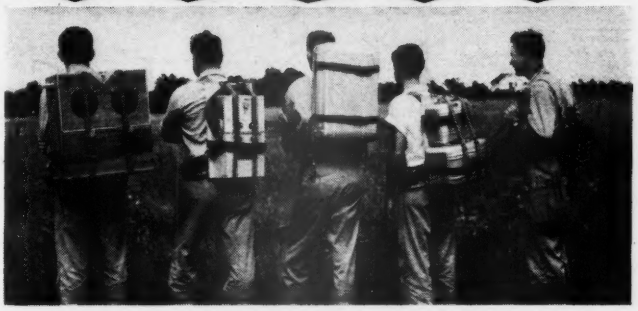

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GA-11 AMPLIFIERS— GAIN: 120 db (1,000,000). Do not require preamplifiers. FILTERS: Two section LC for low frequency rejection; one section LC for high frequency rejection. AGC: Unusually wide range which prevents distortion from high input levels. HERMETIC SEALING: All critical parts (capacitors, resistors, transformers, and chokes) are contained in truly hermetically sealed cans. TUBES: Are not critical as to matching and are readily replaceable. PLUG-IN CONSTRUCTION: Individual amplifiers may be replaced by removing two screws. No soldering is necessary. INDIVIDUAL SUPPRESSION• INDIVIDUAL AMPLITUDED CONTROLS• RESISTIVE OUTPUT MIXING.

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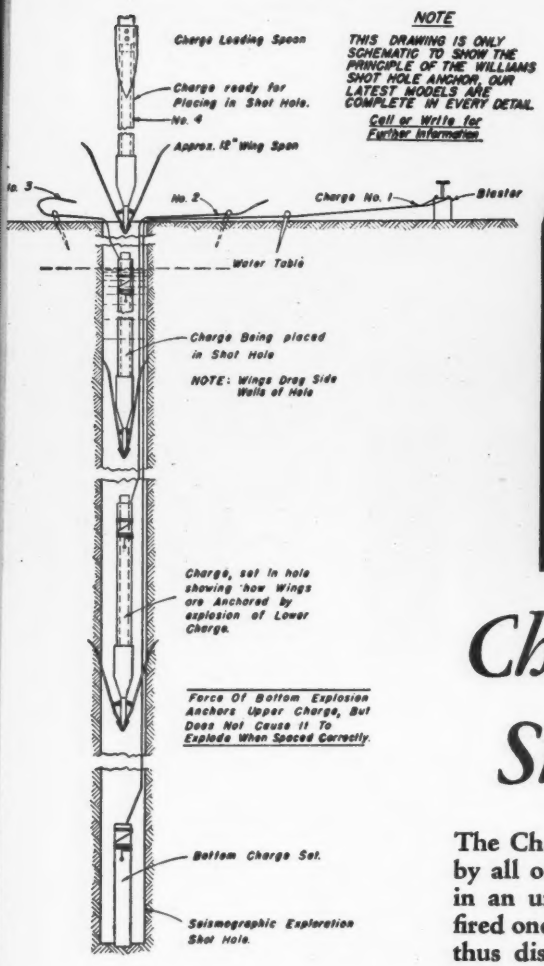
NOTE
THIS DRAWING IS ONLY SCHEMATIC TO SHOW THE PRINCIPLE OF THE WILLIAMS SHOT HOLE ANCHOR, OUR LATEST MODELS ARE COMPLETE IN EVERY DETAIL.
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Charge ready for Placing in Shot Hole.
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Approx. 12" Wing Span
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Charge No. 1
Blaster
Water Table
Charge Being placed in Shot Hole
NOTE: Wings Drag Side Walls of Hole
Charge, set in hole showing how Wings are Anchored by explosion of Lower Charge.
Force Of Bottom Explosion Anchors Upper Charge, But Does Not Cause It To Explode When Spaced Correctly.
Bottom Charge Set.
Seismographic Exploration Shot Hole.

Patent Number 2,450,366

Charge Anchors vs. Shot Hole Casing

The Charge Anchor embodies means and methods whereby all of the charges may be located at the desired points in an uncased bore and separately anchored therein and fired one at a time at desired intervals from below upwardly; thus dispensing with casing in the hole and correspondingly reducing the time and expense necessary to case the bore and to thereafter withdraw the casing.

Better results can be obtained in loose or soft formations; such as sand, silt, gravel, soft clay, etc. More profiles at less cost and less work; in some cases Anchors will cut the cost as much as 75% per hole.

Often it is difficult to use casing because sand fills the pipe after the first shot is fired. We can defeat this problem.

If you want two shots or more in soft formations, call us for a demonstration in the field. There will be no charge except regular sales price of our Anchors; and if the method does not work, there will be no charge.

This method is past the experimental stage. It has been in use by numerous crews for a period well over three years. Names of satisfied customers can be supplied upon request.

This method is ideal for formations found in South Texas, Louisiana, & Mississippi with charges up to 25 pounds per shot.

Take advantage of this valuable method.

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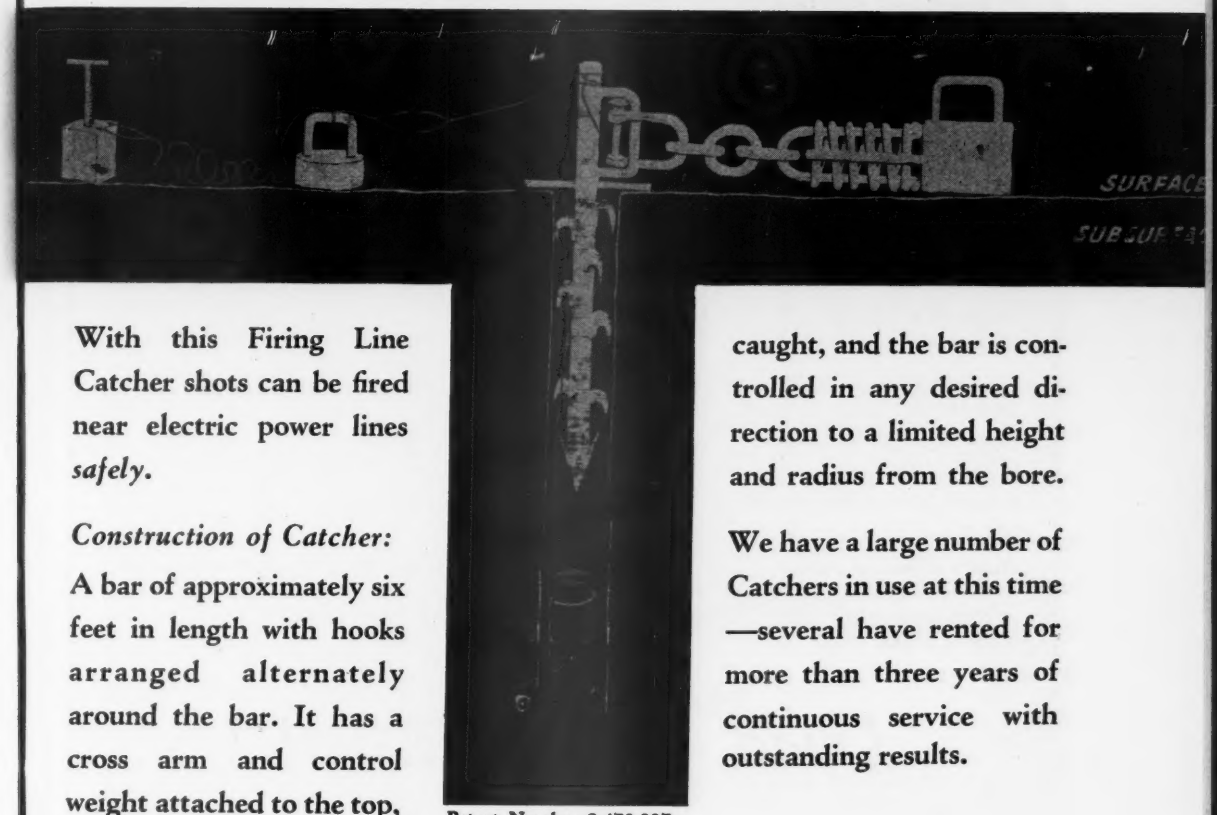

With this Firing Line Catcher shots can be fired near electric power lines *safely*.

Construction of Catcher:

A bar of approximately six feet in length with hooks arranged alternately around the bar. It has a cross arm and control weight attached to the top, and also a circuit breaking weight.

Patent Number 2,472,997

The catcher is designed to be expelled from the hole under hard shots and hole blow. At upward movement the circuit is positively broken, wires are caught, and the bar is controlled in any desired direction to a limited height and radius from the bore.

We have a large number of Catchers in use at this time —several have rented for more than three years of continuous service with outstanding results.

Firing Line Catchers are not for sale. They are placed with crews on a rental basis of $25.00 per month and a minimum of four months rental.

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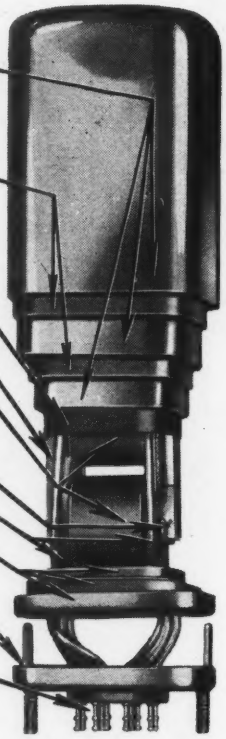
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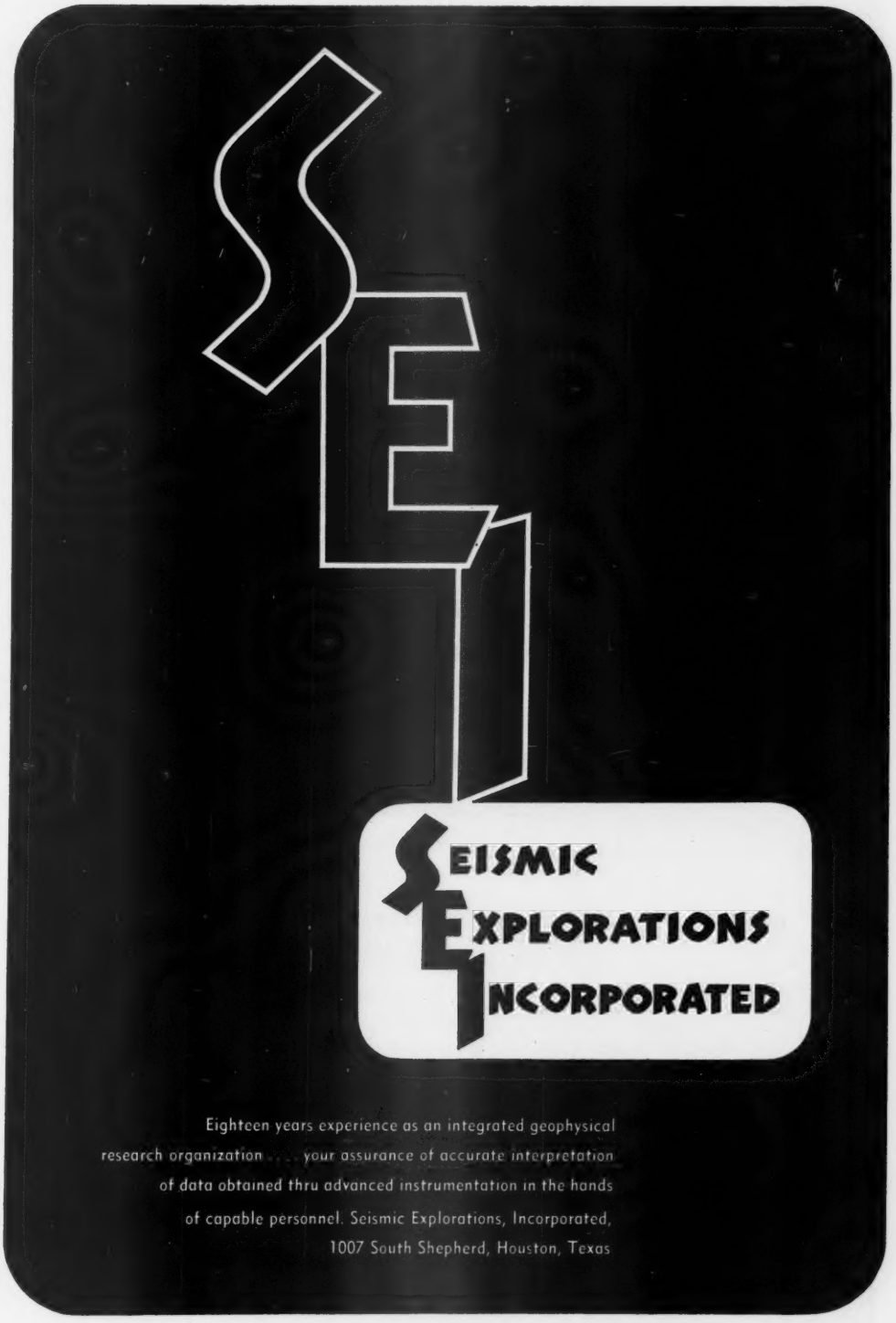
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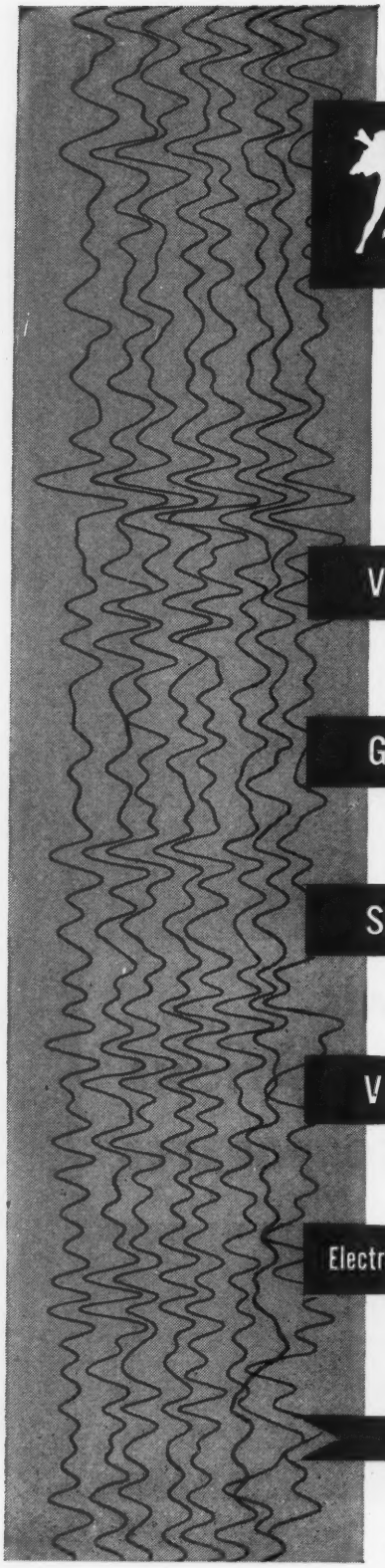

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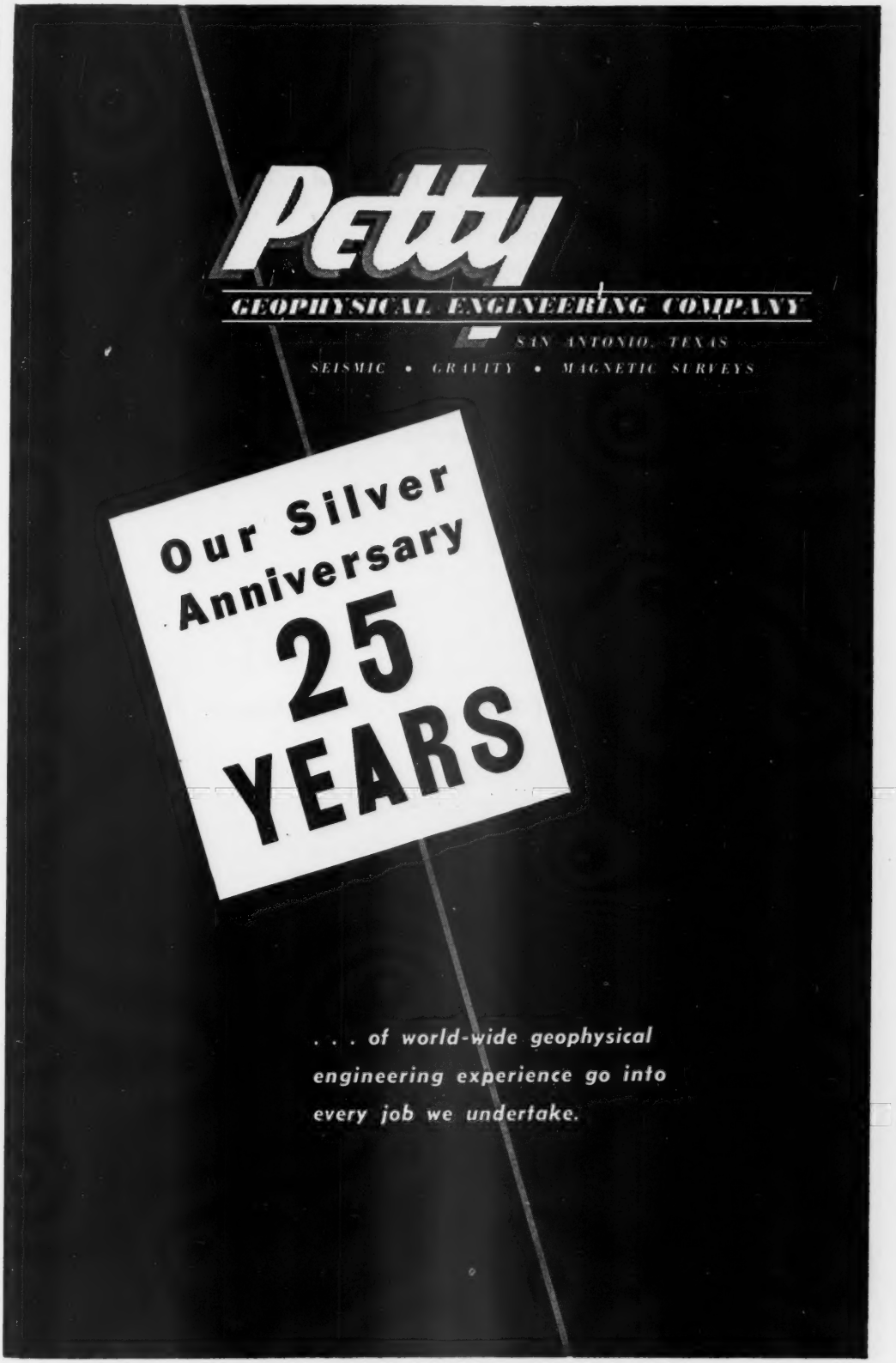
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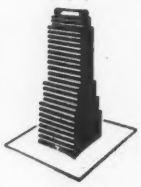

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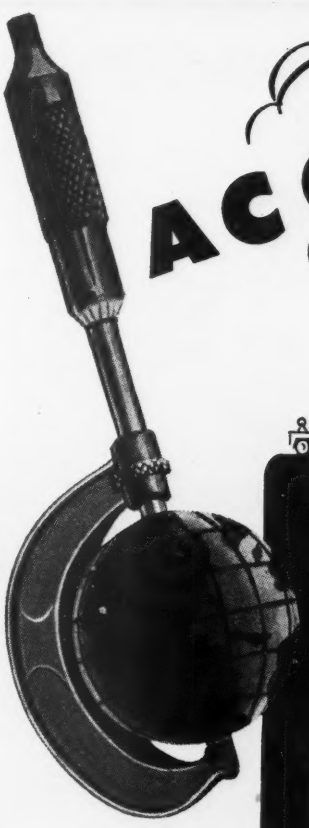

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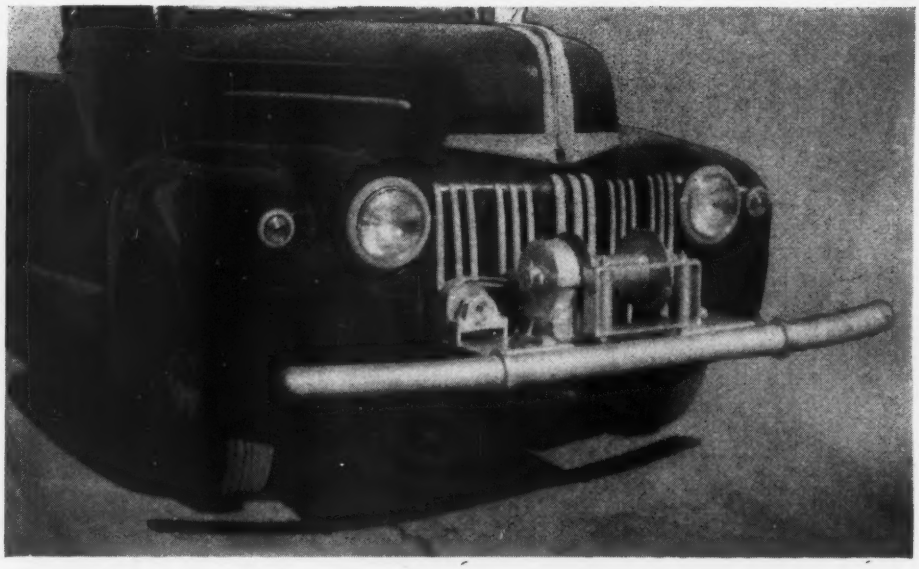

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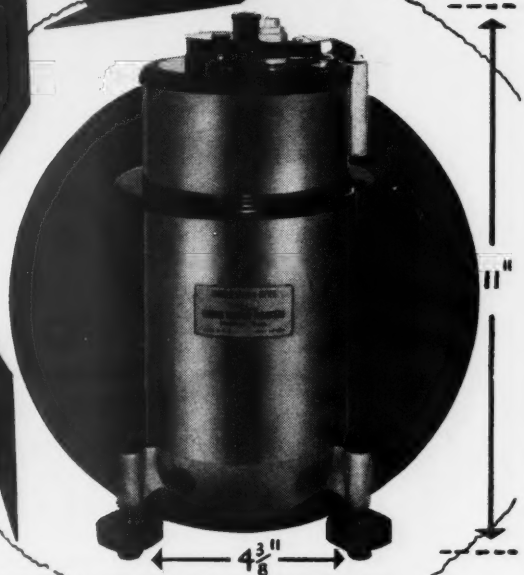

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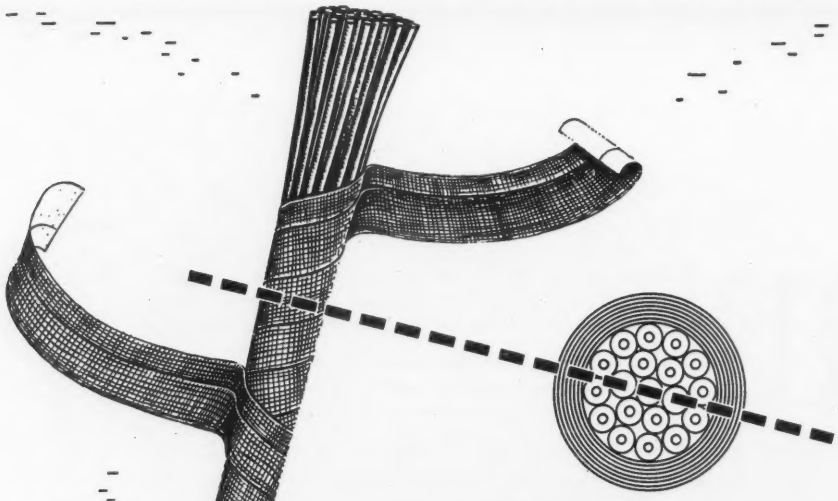

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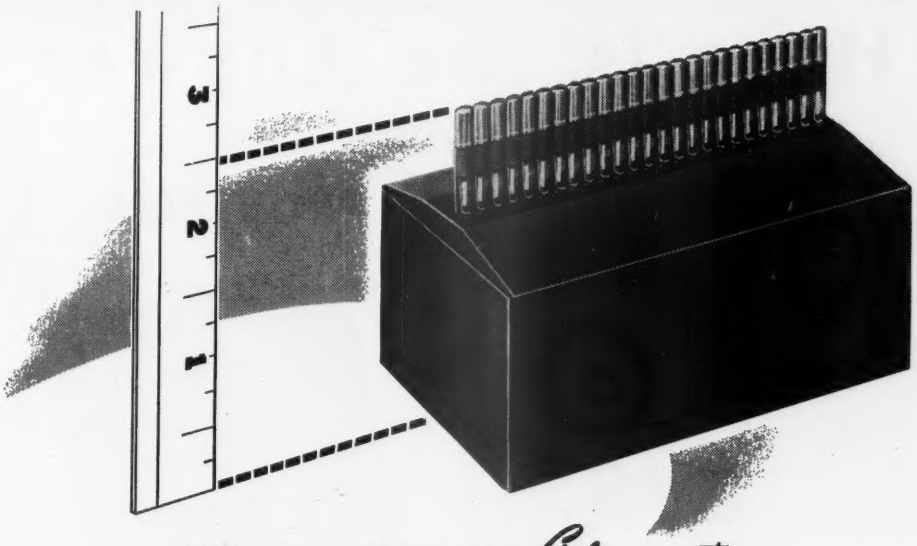

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Bit Size: 8¾"
Spacings: AM = 16"
AM' = 64"
AO = 18' 8"

LOG ANALYSIS

1) Water saturation S

R_t = 8.5 ohms

Departure curves are necessary to establish the value of R_t in the sand from 10,128' to 41' because of bed thickness.

R_o = 1.2 ohms in adjacent wells where the sand is below water level.

$$S = \sqrt{\frac{1.2}{8.5}} = 38\%$$

2) Formation water resistivity R_w

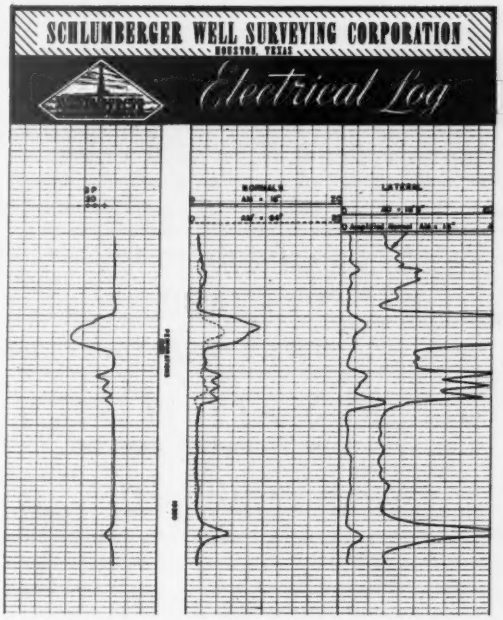
with $SP = -70 \log_{10} \frac{R_m}{R_w} = -60$ mv.,

R_w = .076 ohms @ B.H.T.

3) Porosity p

$$F = \frac{R_o}{R_w} = \frac{1.2}{.076} = 16$$

$$p = \sqrt[m]{\frac{1}{F}} = 21.5\% \quad \text{for } m = 1.8$$



CORE ANALYSIS

Average Porosity	24.3%
Average Permeability	248 md.
Residual Water	48.7%
Residual Oil	11.1%
Total Fluids	59.8%
Connate Water	37%

PRODUCTION RESULTS

Production Section:	10138—43'
Production Potential:	194.5 BOPD 37° API
Gas/oil ratio:	1141/1
Water:	25.1%

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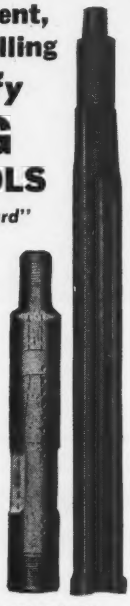

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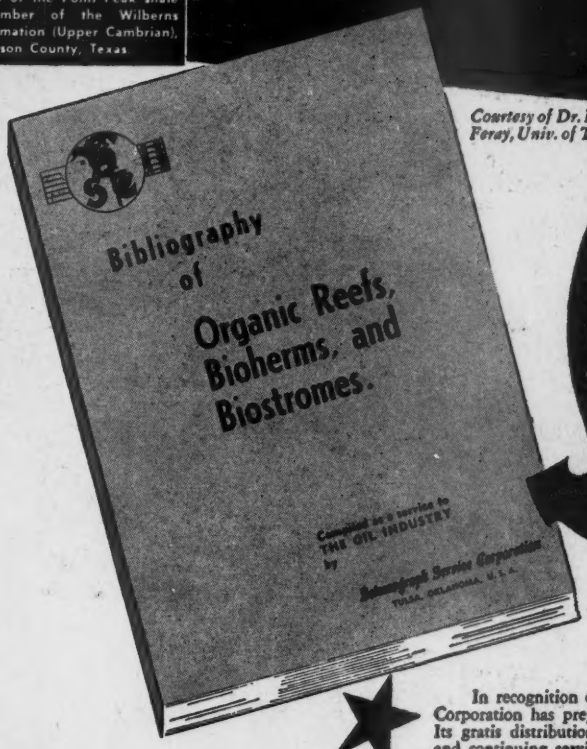
Stromatolitic bioherm at the top of the Point Peak shale member of the Wilberns formation (Upper Cambrian), Mason County, Texas.

Courtesy of Dr. D. E. Feray, Univ. of Tulsa



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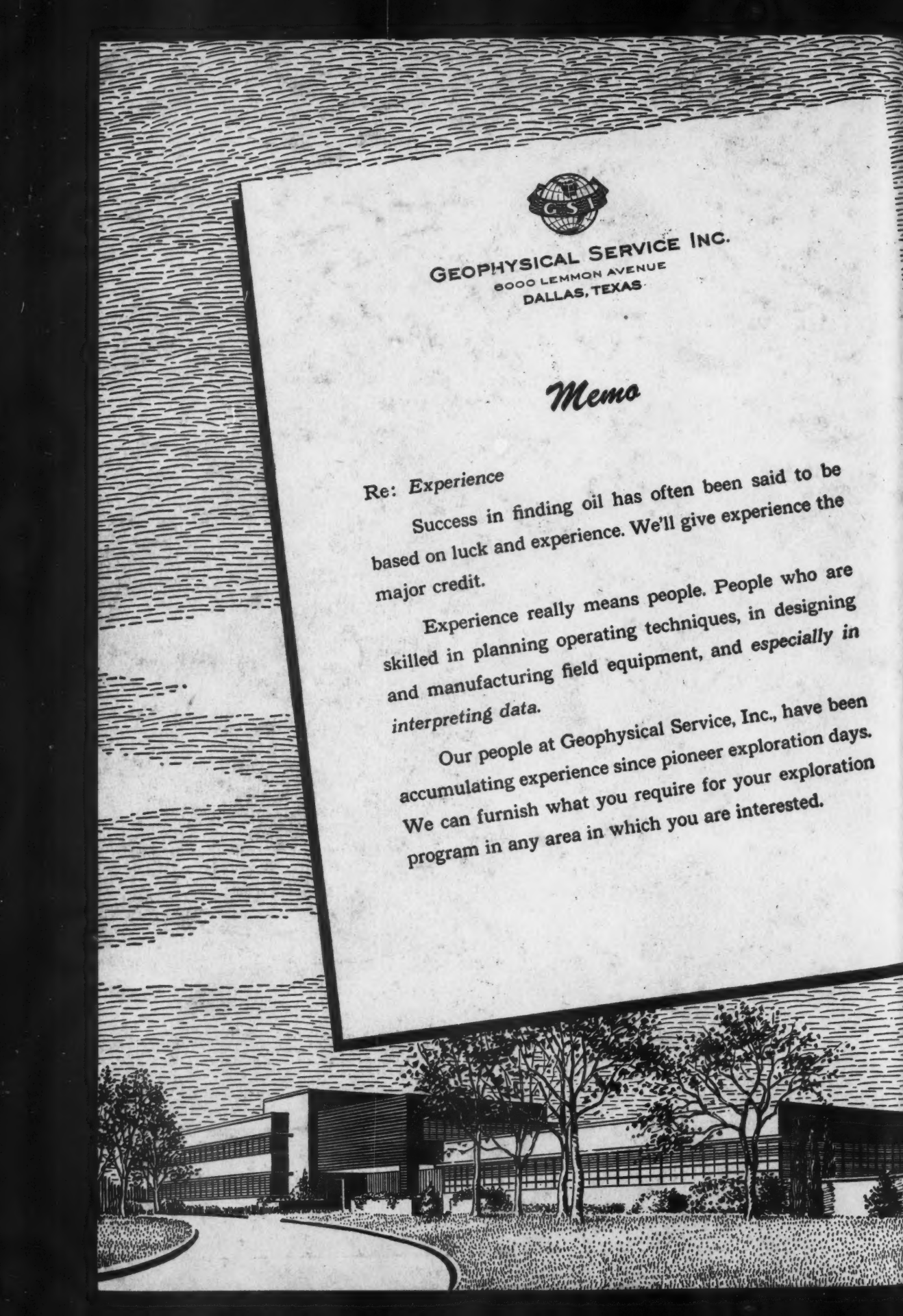
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